NONPOINT SOURCE POLLUTION MODELING

OF THE OYSTER RIVER

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ABSTRACT

The Water Analysis Simulation program (WASP) was applied to the tidal Oyster River, New Hampshire. WASP is a personal computer-based, compartmentalized water quality model with branched one-dimensional links between nodes. The tidal Oyster River is 2.8 miles long, has a mean tidal height of 6 feet and a peak tidal current of 1 knot. Programs within the WASP package were applied to the system, calibrated and verified using previously obtained field data.

The tidal hydrodynamics were analysed first to predict currents and sea levels which served as input to the water quality programs. Salinity distribution was modeled next to calibrate mixing parameters. Bacteria simulations included predictions for steady state tidal conditions with average freshwater tributary discharge, a point source release from a waste water treatment plant, and a once-a-year rainfall event. Dissolved oxygen was modeled to predict the impact of the treatment plant (very small) and the rainfall event (very large in the upper river). The "flushing time" of the river was found to be 3 days. The distribution of total dissolved nitrogen and that of phosphate, due to the tributary and treatment plant loadings, were computed for average conditions.

In general, the trends and processes were reproduced well by WASP. The field data, however, exhibited some scatter, and the differences between point measurements and volume-averaged predictions became apparent.

INTRODUCTION

PURPOSE

With the construction and upgrading of wastewater treatment facilities in communities along tributaries of NH'S Great Bay/Pisctaqua River estuarine system, nonpoint source (NPS) pollution has become the significant contamination problem. This has occurred in the Oyster River which is representative of the six tidal rivers that enter either Great Bay, Little Bay or directly into the Piscataqua River (see Fig. 1). These tidal rivers are typically dammed within an inland town or city and have a treatment plant just downriver from the dam. The rivers are augmented by several smaller creeks and flow through residential and agricultural land before entering the main system. Like the others, the Oyster River is heavily used for recreational boating, fishing and swimming in spite of having continued pollution problems. A recent field study indicates that NPS pollution arising from private on-site wastewater systems as well as storm water runoff are the prime causes of this contamination.

In this study we address this problem by implementing, calibrating and verifying a water quality computer model for the tidal part of the Oyster River. The model is the EPA's Water Analysis Simulation Program (WASP), a personal computer based simulation for toxic substances, nutrients, dissolved oxygen and bacteria. This one-dimensional, compartmentalized (box) model accounts for transport and mixing by currents, and includes

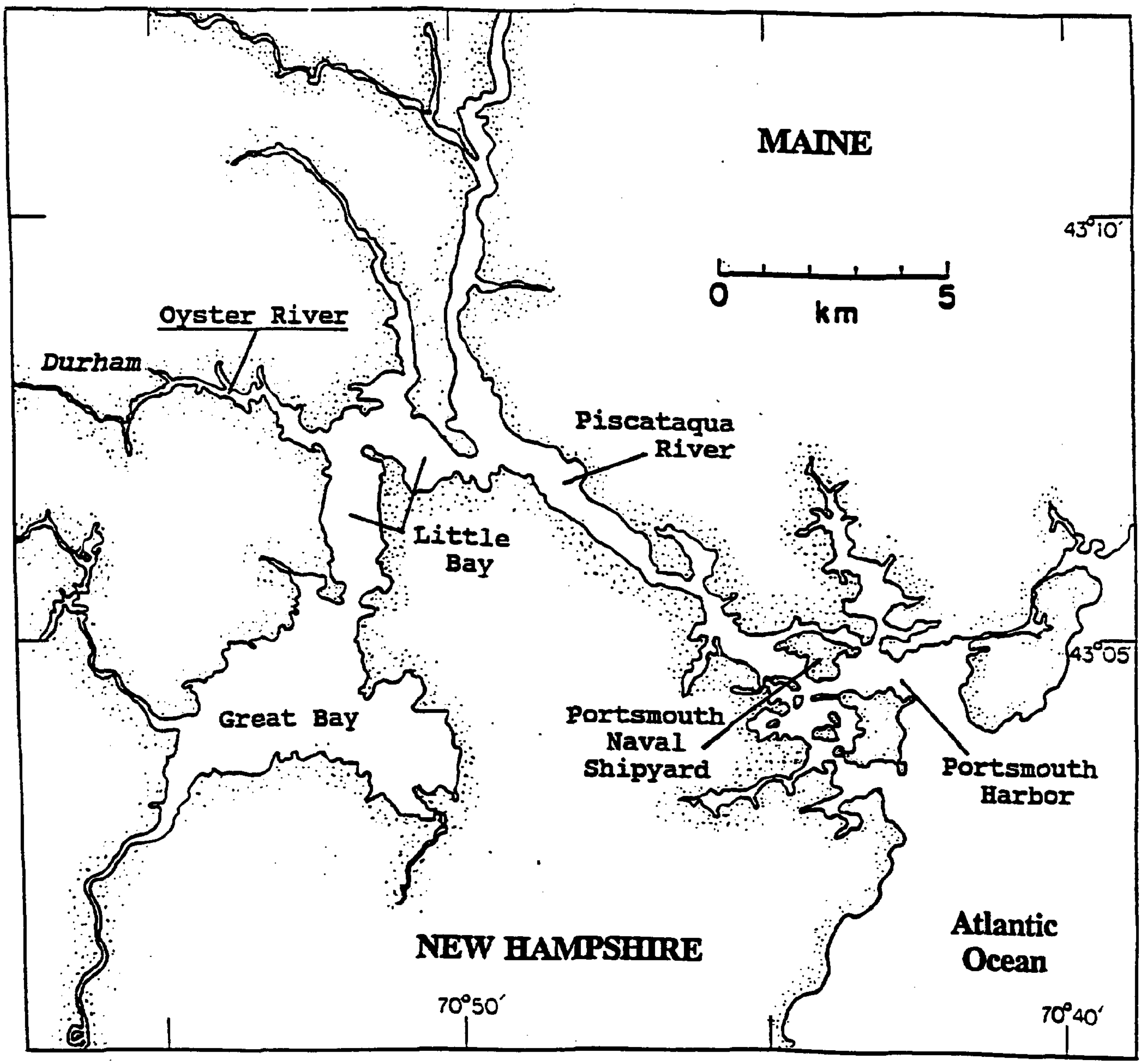

Fig. 1 The Great Bay estuarine system.

chemical and biological processes.

The completed model can be employed to answer questions regarding the effects of changes in land use regulations as well as contributing to the scientific understanding of pollution processes. This information can be employed by state and local authorities for planning purposes. In particular, the NH Office of State Planning (OSP), the NH Department of Environmental Services (NHDES), town boards and ad hoc citizen's groups can make use of this approach.

The presence of NPS pollution in the Oyster River, as well as other parts of the Great Bay/Piscataqua River system, has been described by the NH DES (1989), Flanders (1989), the NH Fish and Game (1991) and by Jones et al. (1992). The setting of priorities and the need to develop management plans to mitigate this problem have been discussed by the NH DES (1989, 1992). The application of WASP to the Oyster River provides an important tool for addressing these issues.

OYSTER RIVER PROBLEM

The issue addressed in this study is NPS pollution in the tidal portion of the Oyster River, Durham, NH (see Fig. 1). The Oyster River is representative of six tidal rivers that drain into the Great Bay estuarine system and is typical of many of the smaller New England estuaries. The existence of NPS pollution problems in the Great Bay drainage area in general and the tidal Oyster River in particular have been well documented by the NH Department of Environmental Services (NHDES) (1989), Flanders (1989) the NH Fish and Game Department (NHF&G) (1991) and by Jones et al. (1992).

The tidal Oyster River starts at the Mill Pond dam (see Fig. 2) where the discharge over the dam is normally 10 cfs but can increase by over an order of magnitude during storm or spring runoff events. The watershed drained by the freshwater Oyster River is nearly 20 square miles. Downriver from the dam is a publically owned treatment works (POTW) which serves the town of Durham. Several creeks enter the river draining a combined watershed area of about 11 square miles including urban, residential and agricultural areas. The mouth of the Oyster River (entering Little Bay) is 2.8 miles from the dam and is subject to a mean tidal height of 6 ft and a peak tidal current of 1 knot.

The Oyster River has recently been the subject of a two-year field program that was carried out by S.H. Jones and R. Langan of the Jackson Estuarine Laboratory, UNH. Problems identified include fecal-borne bacterial contamination, high levels of ammonia and insufficient dissolved oxygen. Contamination has been attributed to on-site wastewater systems, agriculture and urban runoff. During the first year, the main river channel was sampled with limited additional data taken in tributaries as discussed by Jones and Langan (1993). Water samples were taken throughout the year and were analyzed for fecal coliforms, enterococci, ammonia,

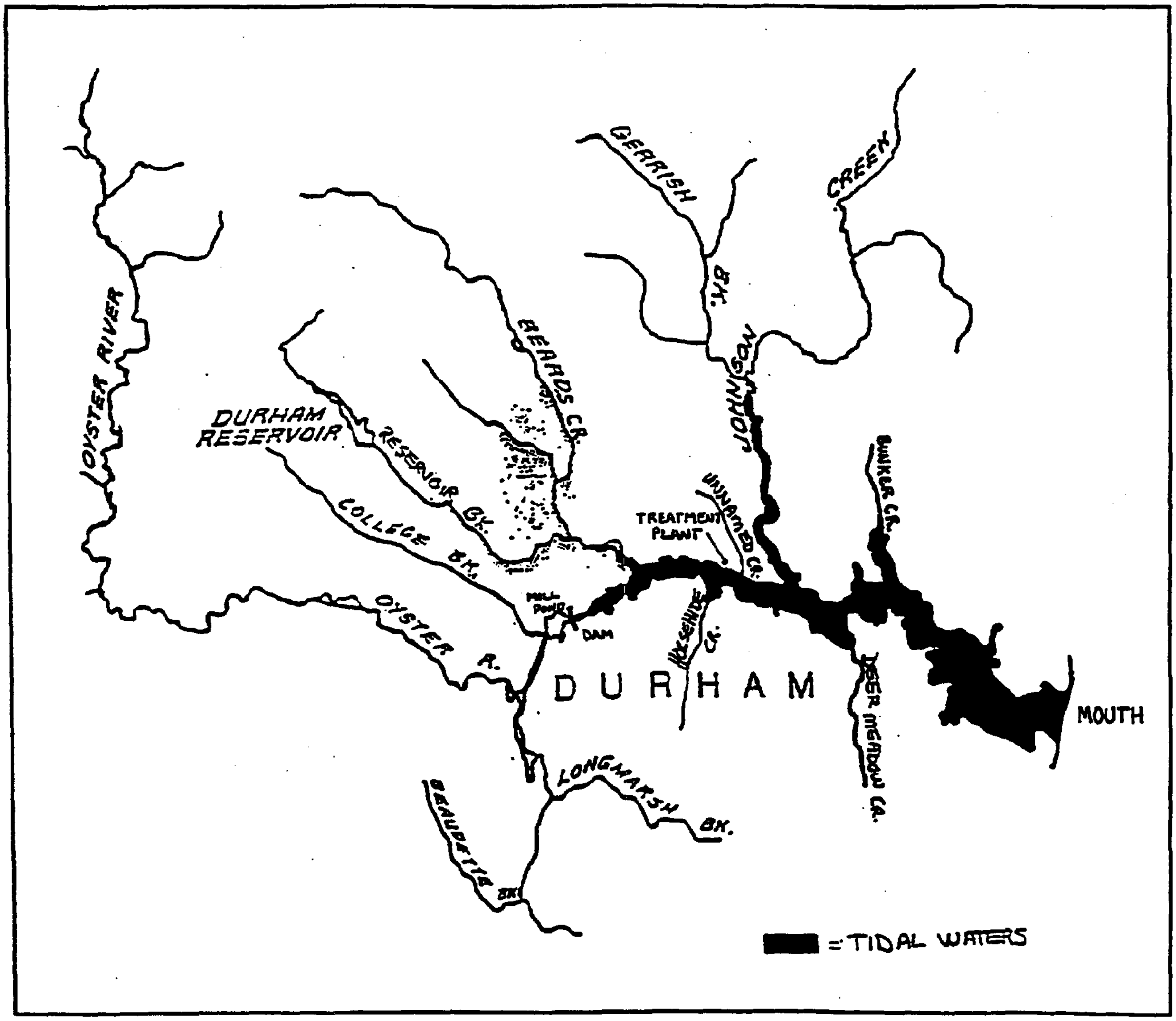

Fig. 2 The Oyster River, New Hampshire

nitrate, phosphate, pH, salinity, temperature, chlorophyll a, dissolved oxygen and suspended solids. The next year, the focus was on tributary input from Beard's Creek and Johnson Creek (see Fig. 2) and the POTW plume (Jones and Langan, 1994).

In this study, we built on the observation effort by applying a water quality model to the system. The model, WASP, is described by Ambrose et al. (1993a, b) as a computer simulation which can be used for predicting concentrations and transport of toxic substances, nutrients, dissolved oxygen and bacteria. This is a branched, one-dimensional, compartmentalized (box) model which accounts for transport by currents, mixing by dispersion and turbulence, resuspension and settling of sediments, as well as chemical and biological processes. In previous work, we have applied WASP5 to the main Great Bay/Piscataqua River system to predict lead transport and have found the model to be suitable for pollution investigations such as this study.

OBJECTIVES

The objectives of the this study were to:

1. Implement WASP for the Oyster River by specifying channels and compartments according to the system's geography, bathymetry, freshwater input and tides. The model was set up to predict salinity, bacteria, nutrients and dissolved oxygen.

2. Calibrate the model using data from the two-year field program. Model coefficients and parameters were optimized for consistency between model predictions and measured concentrations.

3. Conduct application studies to evaluate the impact of typical loadings to the system. Several scenarios of interest originated from specific requests of a state agency and a citizens' group. In addition, the model was used to determine river sensitivity to changes in individual source loadings and to determine their relative importance.

APPROACH

The tidal Oyster River system was modeled using WASP which allows the time varying processes of advection, dispersion, point and diffuse loadings and boundary exchanges to be modeled. The model operates on tidal time scales to allow examination of the dynamics of the system.

WASP was implemented by modeling the Oyster River system as a sequence of compartments with interconnecting "channels". The modeling was based on existing maps and depth data. Fluid flow boundary conditions and freshwater input, were specified from previous UNH work. Dispersion (mixing) coefficients, process parameters and coefficients were estimated initially. Final values were determined during the calibration phase.

During model calibration, coefficients and parameters were adjusted to give the best fit between model predictions and the available field observations. The first step was to calibrate the hydrodynamic component of the program. Friction parameters, channel cross-section areas and effective depths were adjusted so that tidal elevations, currents and volume rates of flow agreed with field observations reported by Shanley (1972), Garrison (1979), Schmidt (1981) and Swift et al. (1991).

Next, dispersion coefficients were determined by calibrating to the observed salinity distribution reported by Shanley (1972), Garrison (1979) and Schmidt (1981). Salinity is conservative, so it is a good test of a model's ability to predict transport processes without the added complication of sources and sinks.

Bacteria and chemical process parameters were then established using the appropriate measurement data from the Jones and Langan field program. NPS loadings, including input from private on-site wastewater treatment systems, agriculture and urban runoff, were incorporated as loadings from creeks entering the tidal river. Point source load from the Durham POTW is taken into account since it can be the dominant factor for some parameters. (This study did not, however, include developing watershed models.)

Sensitivity studies were conducted by varying the strength of individual sources and source types and predicting the impact on river contamination levels. Applications include steady state scenarios during average conditions, accidental sewage releases and rainfall events.

WASP

STRUCTURE

A concise description of the personal computer-based programs available through WASP is provided in this chapter (especially those features important in modeling the Oyster River). The complete documentation is available in reports by Ambrose et al. (1986, 1993a,b). The current version of the software is WASP5 which has been used in this study.

WASP consists of a package of three water quality related programs - DYNHYD, TOXI and EUTRO. DYNHYD is a hydrodynamic model for calculating current and water surface elevation. TOXI is set up to model toxic substances but can be used for bacteria, any conservative substance or substances having decay characteristics. EUTRO is used for eutrophication processes involving dissolved oxygen, biological oxygen demand and nutrients. EUTRO offers a full range of model sophistication depending on the level of complexity desired.

DYNHYD is run separately and prior to the other two in order to calculate current and water levels. The pre-calculated current and water level file then serves as input to TOXI and EUTRO.

In WASP the geometry of the system is represented by an array of compartments (nodes or boxes) connected by conduits (links or channels). Storage and chemical/biological processes take place within the nodes, and properties are assumed uniform within the node volume. Transport takes place between nodes through the links. Flow and dispersion through the links is one-dimensional.

The link-node array may, however, be one-dimensional or branched in two or three dimensions.

The link-node array used in this study is shown in Fig 3. The node locations were chosen to correspond to Jones and Langan main channel sampling locations, the POTW and the two major tributary inlets of Bunker Creek and Johnson Creek. Additional nodes were also introduced to maintain an approximately uniform distance between nodes.

THEORY

For DYNHYD, the basic governing equations are conservation of mass (continuity) and the equation of motion (Newton's Second Law). Conservation of mass is applied to the water within the node volumes. The one-dimensional equation of motion is applied to the link flow between nodes. Terms account for local acceleration, advective acceleration, slope-induced pressure gradient and friction. Friction is parameterized using a user-specified Manning number. The ordinary differential equations governing the dynamics are solved using a Runge-Kutta approach.

For TOXI and EUTRO, the basic equation is the conservation of mass law applied at each node to each substance considered. Transport processes of advection and dispersion between nodes are incorporated. Dispersion coefficients are user-specified and serve as an important calibration parameter. Within each node volume, production, decay and speciation terms and auxiliary equations may be included depending on the substance(s)

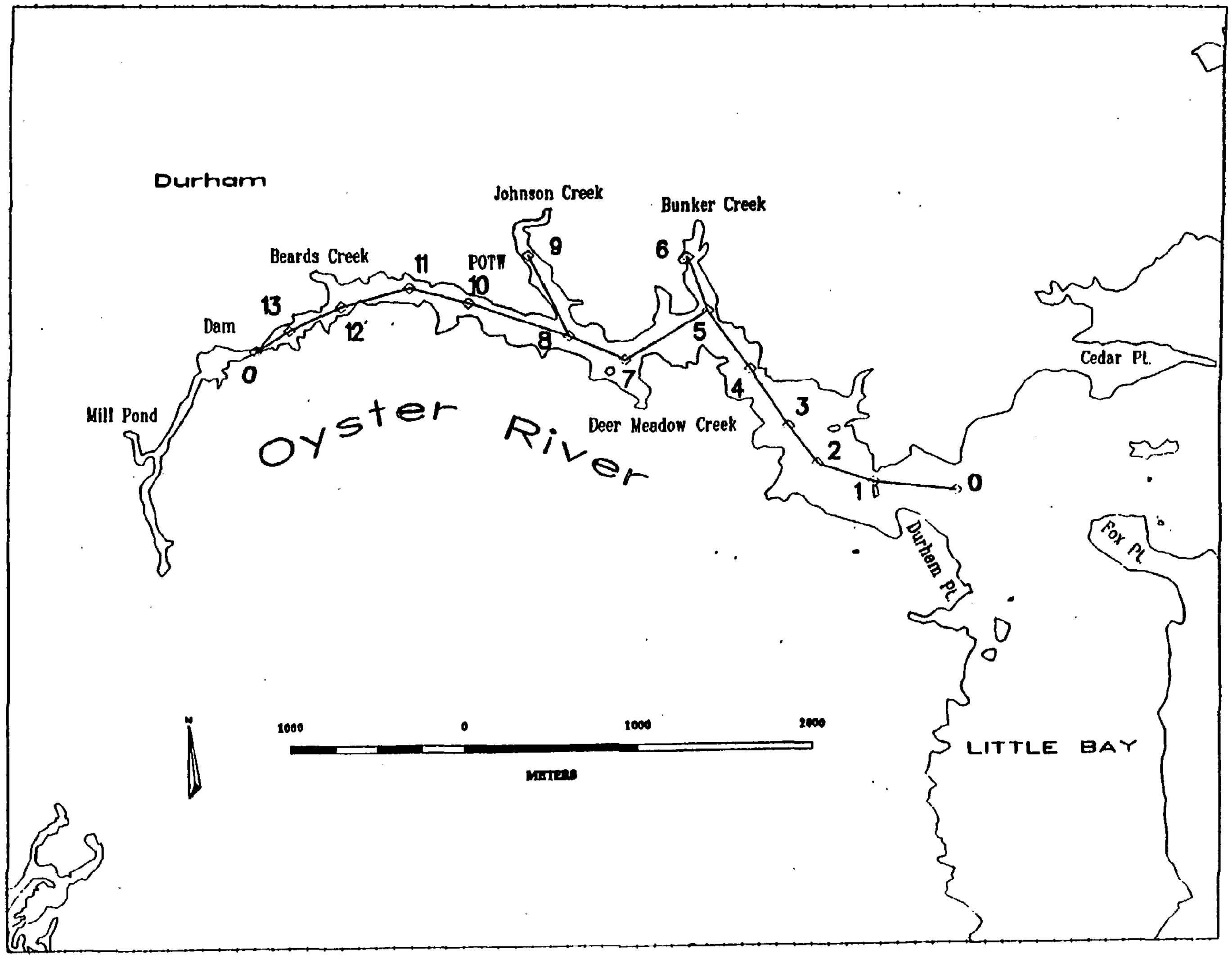

Fig. 3 Node locations for TOXI and EUTRO. DYNHYD uses the same nodes but are numbered 1 - 15 starting at the mouth.

considered. To solve these equations, WASP uses an explicit one-step Euler solution. The potential for instability or numerical dispersion is controlled by manipulating the time step.

INPUT/OUTPUT

Data Requirements

In all cases, information on the simulation geometry must be input. This includes node planform areas and depth along with link orientation, length, cross-section area and depth. The connectivity between nodes and links in the grid must be specified.

In general, dependent (state) variable initial conditions and boundary conditions are also necessary. Pollution and other loadings to the system are critical input data as well. Bio-chemical parameter values and equation coefficients need to be entered to quantitatively specify the processes to be simulated. Simulation control information, such as start and stop time, time step and print interval, is also part of the input file.

For DYNHYD, water level at open boundaries must be input. This allows, for example, the system to be driven by user-specified tides which are critical to the Oyster River model. Freshwater discharge from tributary (or other sources) is similarly an important data requirement. Specifying the Manning number on a channel by channel basis is necessary and is normally employed to tune the the hydrodynamic model calibration.

For TOXI and EUTRO, pollution initial condition and boundary condition concentrations are required as well as pollution loading from tributaries, point or distributed sources. Dispersion coefficients and mixing lengths are specified for each channel and serve as a principal means for model calibration (particularly for conservative substances). When utilized, decay rates, partition coefficients and reaction rates may be entered. In the case of an EUTRO application, regeneration coefficents, saturation values and interaction coefficients between dissolved oxygen, biological oxygen demand and nutrients can be quantified in the input file. Specific data requirements depend on the level of complexity desired.

Calculated Results

Calculated values of each dependent variable for each node (or "segment") at each print interval are stored in an output file. A limited amount of post-processing is available with the WASP package. Segment concentration as a function of time can, for example, be quickly plotted. For higher quality or custom plots, however, it is better to use the output file in connection with a standard spreadsheet or graphics software.

HYDRODYNAMICS

DYNHYD was implemented for the tidal Oyster River and calibrated by comparison with field data. Since this model supplies the necessary current and sea level input to TOXI and EUTRO, it was applied first. Decisions regarding model geometry were, therefore, made at this time. Comparisons with data include low, average and high freshwater tributary discharge conditions.

The link/node grid selected is shown on Fig. 3. The density of segments is greater than measurement sites for any of the field studies any of the models were compared with. Yet node spacing is not so close that segments are distorted in planform nor are there problems with computation time and storage. It should be noted that DYNHYD uses a different node numbering scheme from TOXI and EUTRO as described in the Fig. 3 caption.

The Oyster River dynamics is driven principally by the tides, and the mouth boundary condition was taken to have a tide height of 0.91 m (interpolated from Swift and Brown, 1983) and a semi-diurnal tidal period of 12.41 hours. The simulations were started at high tide with an initial condition elevation of 0.455 m and an initial condition current speed of zero.

Freshwater tributary discharge was input at Bunker Creek, Johnson Creek, Beards Creek and the upper Oyster River (at the dam). Input from other sources (such as the POTW and Deer Meadow Creek) had a negligible effect on current though pollution loadings could be significant. There was some inconsistency in the published literature regarding discharge rates. This was because discharge varies from year to year as well as on a daily and seasonal basis. The calculations described here were based on the 31 year average provided by Shanley (1972) for the upper Oyster River. The tributary imput was then prorated on the basis of relative watershed areas and flow ratios obtained from Jones and Langan (1994).

The standard calibration parameter for DYNHYD is the Manning number which controls bottom friction. In the Oyster River application, however, the tidal response was relatively insensitive to Manning number changes. The principal set of parameters affecting response were channel widths. Effective widths had to reflect the breadth of the deep part of the river channel between the shallow mudflats on each side. The best and proper width was such that the product of width and depth equalled the actual cross-section area. Input files for the three conditions discussed here are provided in the Appendix.

DYNHYD predictions were compared with current data from Shanley (1972), Swift (1990) and Swift et al. (1991) as shown on Figs. 4 - 6. Agreement is good considering that the comparisons are between point measurements in a non-uniform flow field and channel-averaged model predictions. It should also be noted that there is a certain amount of tidal asymmetry, and current depends mostly on the tides and is not sensitive to discharge. For extreme rainfall or snowmelt events, however, discharge can change by more than an order of magnitude, and mean, outflowing current can become more pronounced.

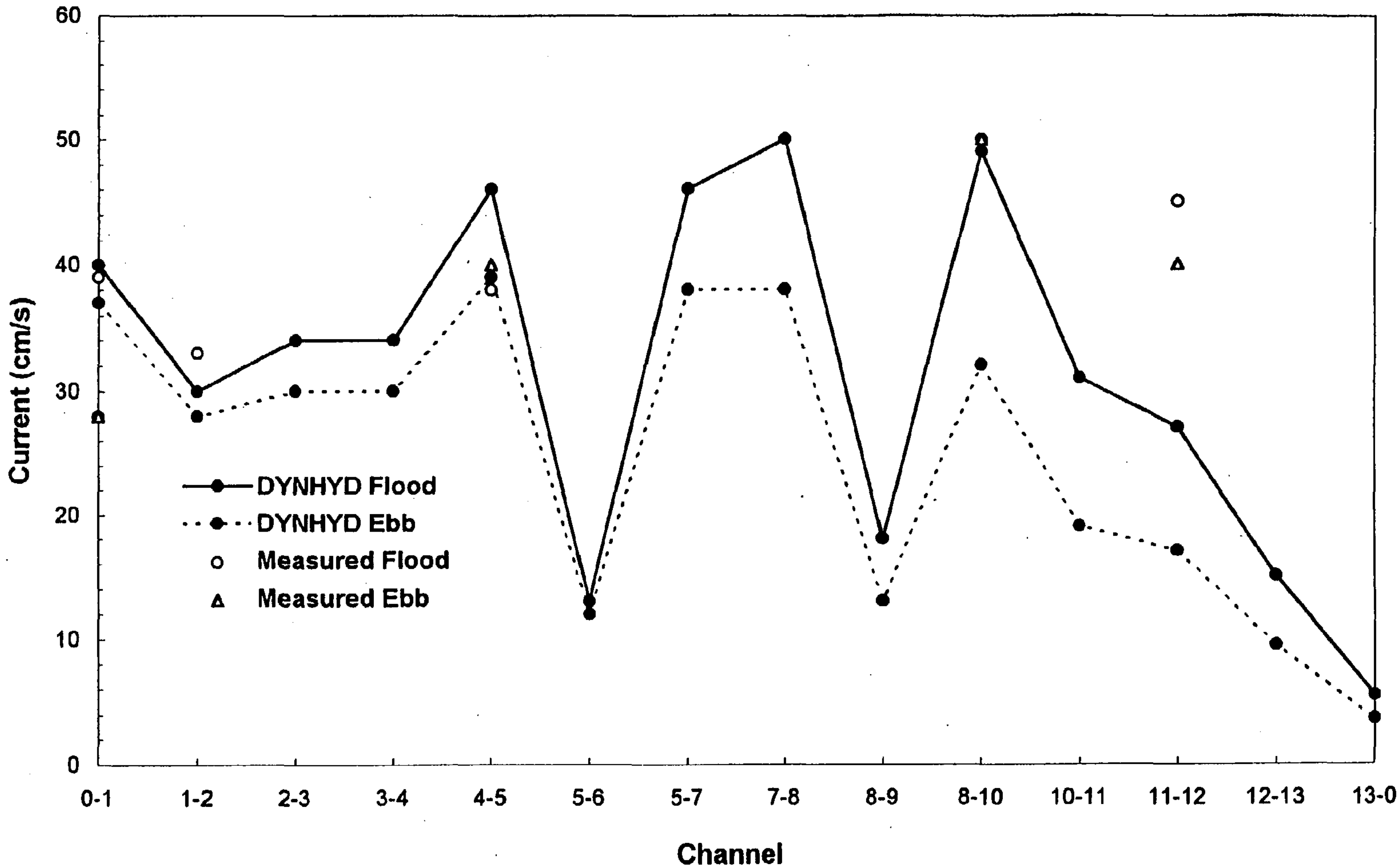

Fig. 4 Computed and measured current during low discharge conditions. Channels are indentified by node end points shown on Fig. 3.

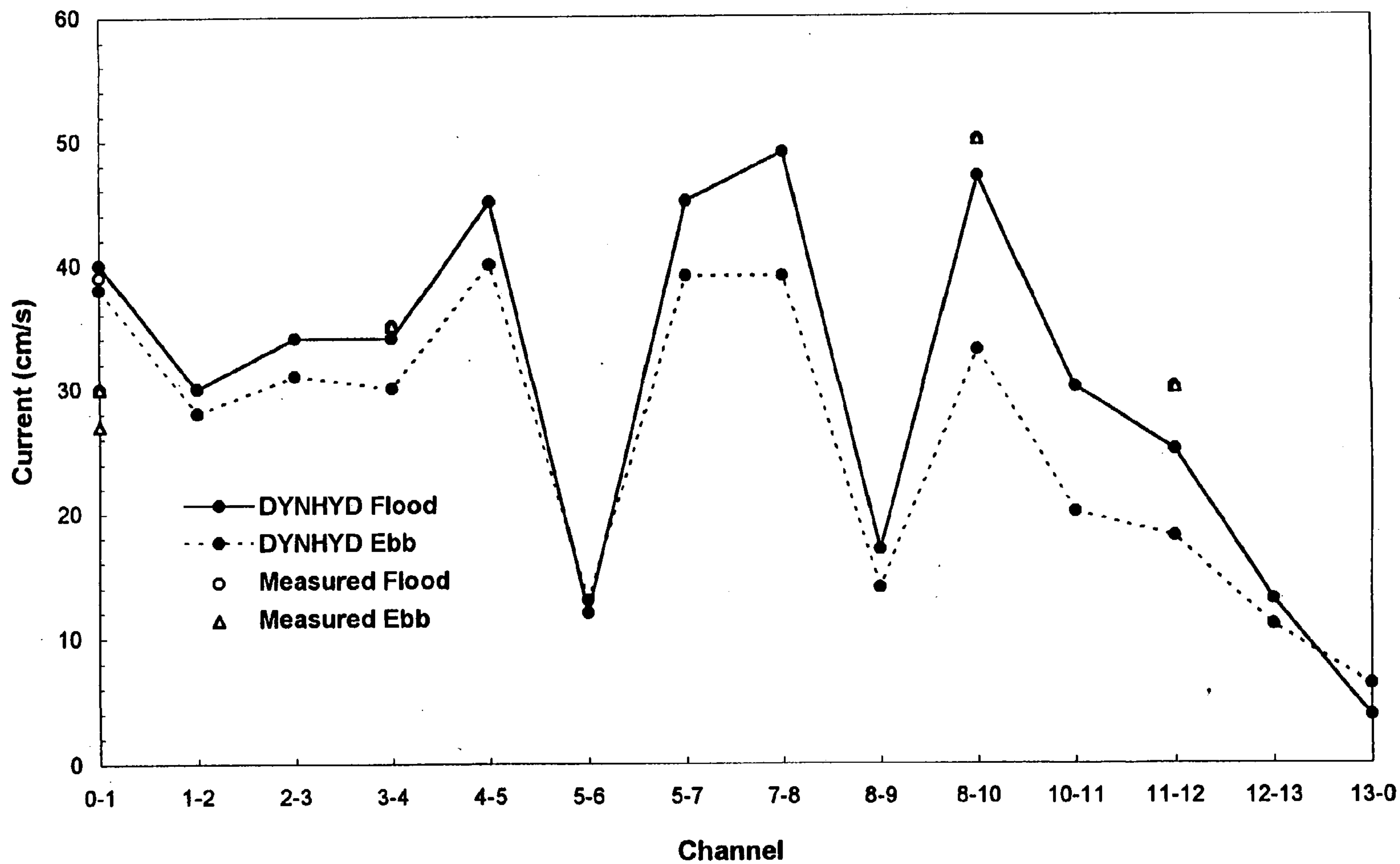

Fig. 5 Computed and measured current during average discharge conditions. Channels are identified by node end points shown on Fig. 3.

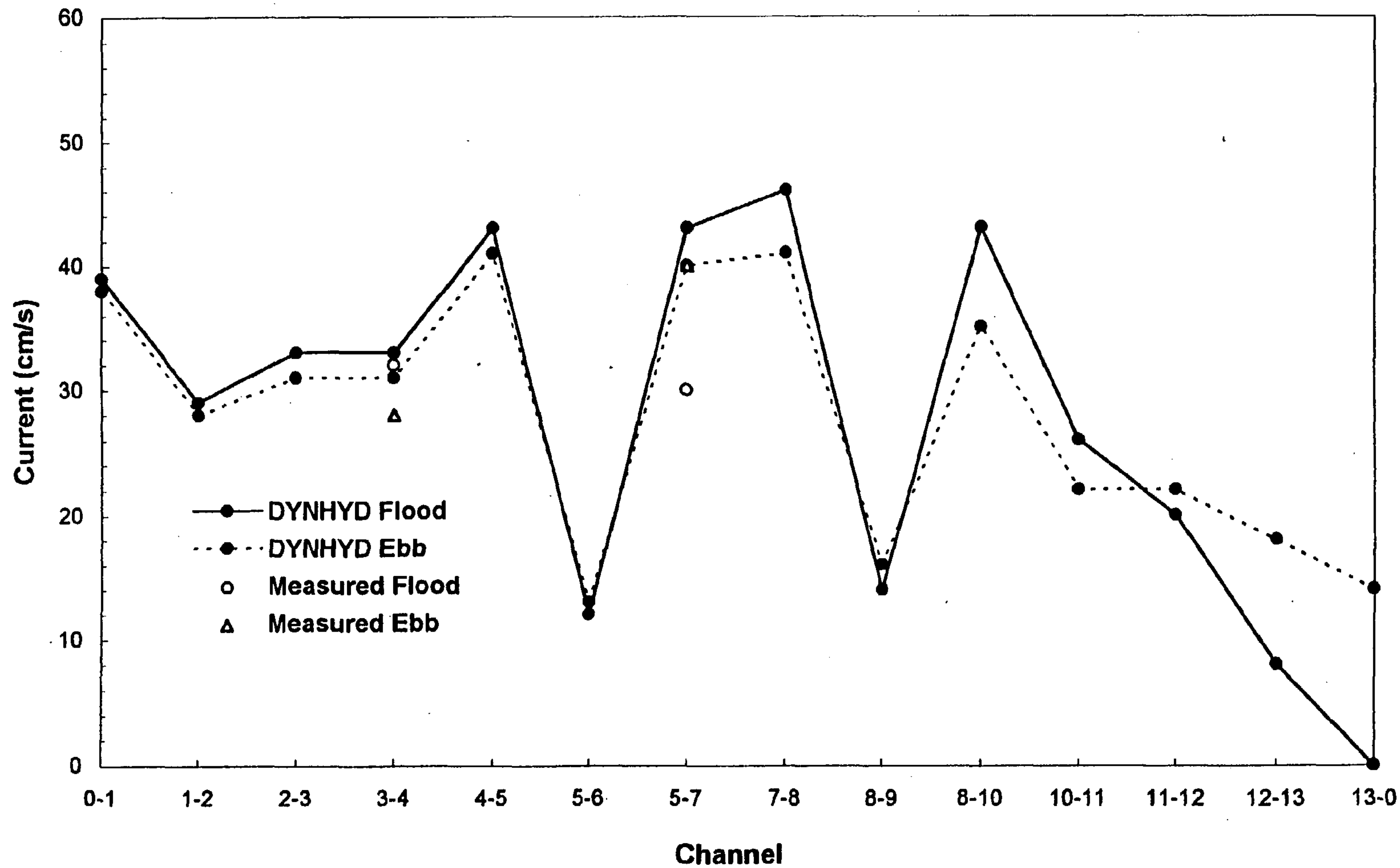

Fig. 6 Computed and measured current during high discharge conditions. Channels are identified by node end points shown on Fig. 3.

SALINITY DISTRIBUTION AND MIXING

The hydrodynamic output files from the DYNHYD simulations were next used with TOXI to model the salinity distribution. Though salinity is important as a fundamental physical/chemical variable, its significance in this study was as a conservative tracer. Salinity was modeled so that dispersion parameters could be calibrated and the transport processes of advection and mixing could be validated. The modeling was done with TOXI having one nonzero dissolved variable, no chemical reactions and no decay. The calibration parameters available were the dispersion coefficient and mixing lengths. The Oyster River studies reported by Shanley (1972) served as the source of salinity data for comparison.

All simulations used the same Fig. 3 grid as the DYNHYD applications (but with the nodes renumbered). Salinity boundary conditions at the mouth and head varied sinusoidally in time between high and low tide values or were constant. The simulations started at high tide with a slight time offset because DYNHYD must run through a full day before TOXI begins its computations. Boundary conditions for low, average and high freshwater discharge rates are provided in Table 1. Initial condition concentrations were specified by interpolating between the starting mouth boundary condition and the starting head boundary condition. No explicit provision was made in TOXI for tributary input. The freshwater dilution effect was incorporated through the current transport and volume changes resulting from

Table 1 Salinity boundary conditions at mouth and head (in parts per thousand).

	Low Discharge	Average Discharge	High Discharge
Mouth High Tide	30.4	28.0	14.2
Mouth Low Tide	29.6	24.5	11.4
Head High Tide	13.3	0	0
Head Low Tide	2.7	0	0

the DYNHYD input file. A dispersion coefficient of 10 was used based on previous WASP applications to similar estuaries. To begin the calibration process, mixing lengths were specified as the corresponding distance between nodes.

The general trend of the Shanley (1972) observations consisted of high salinity penetration through the lower river with a pronounced decrease approaching the head. The physical explanation is increased tidal current mixing in the open sections near the mouth, and inhibited exchange in the narrow, restricted upper channel. To enhance model dispersion in the lower river, mixing lengths (inversely proportional to dispersion transport) had to be decreased in the average discharge conditions simulation. This modification was not necessary for low discharge and high discharge applications. Input files for the three salinity prediction applications discussed are provided in the Appendix.

The comparison between high and low tide predicted salinity distribution and data from Shanley (1972) are shown on Figs 7 - 9. The overall trends are evident and consistent. Discrepancies may again be due to the difference between point measurements and volume-averaged predictions. Another factor is that the Shanley (1972) longitudinal distribution source figures were apparently hand-contour plots derived from the raw data. Nevertheless, the agreement and confidence in the comparison was sufficient to conclude that the optimum mixing parameters had been chosen for subsequent WASP water quality applications.

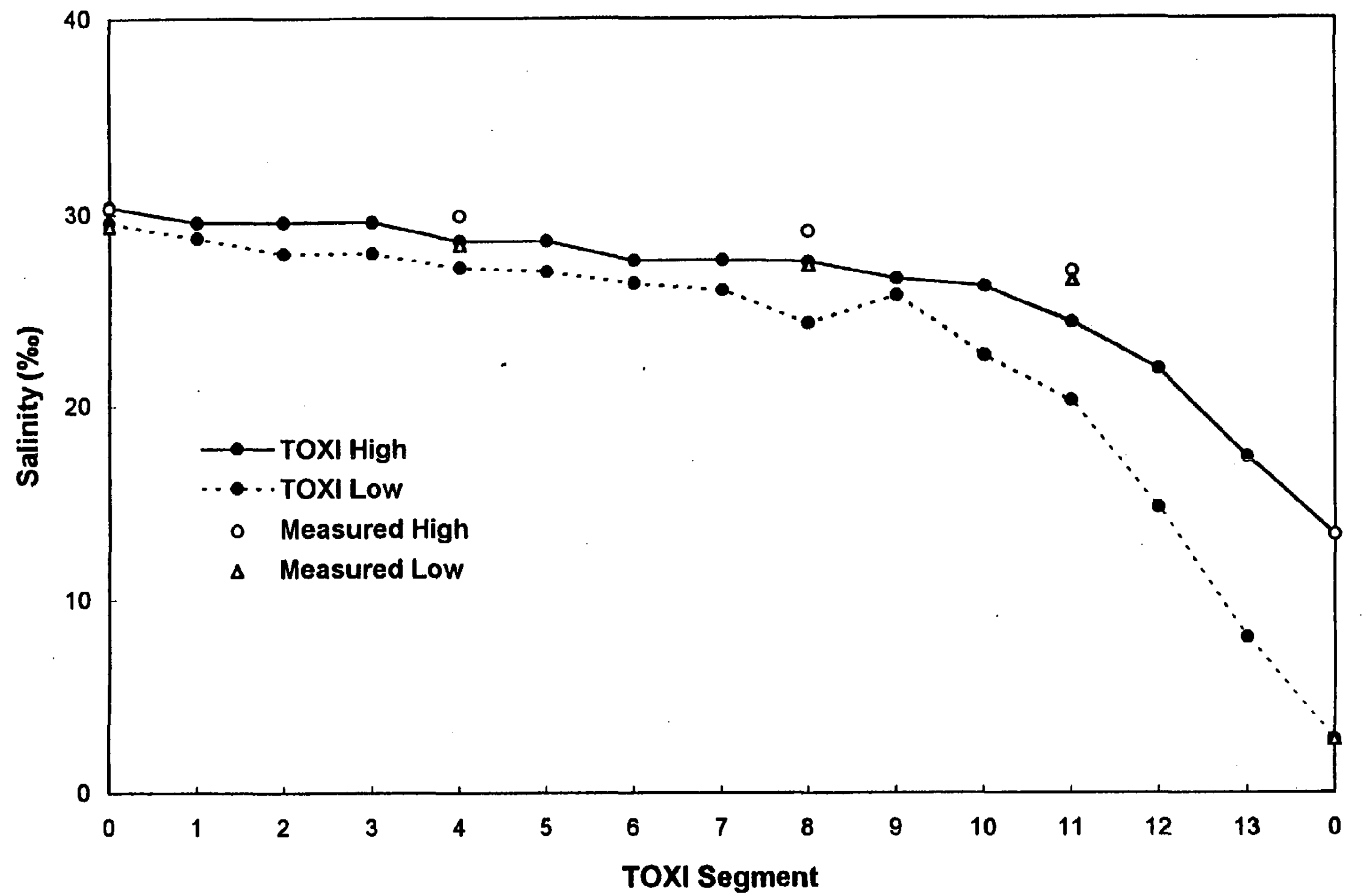

Fig. 7 Computed and measured salinity during low discharge.

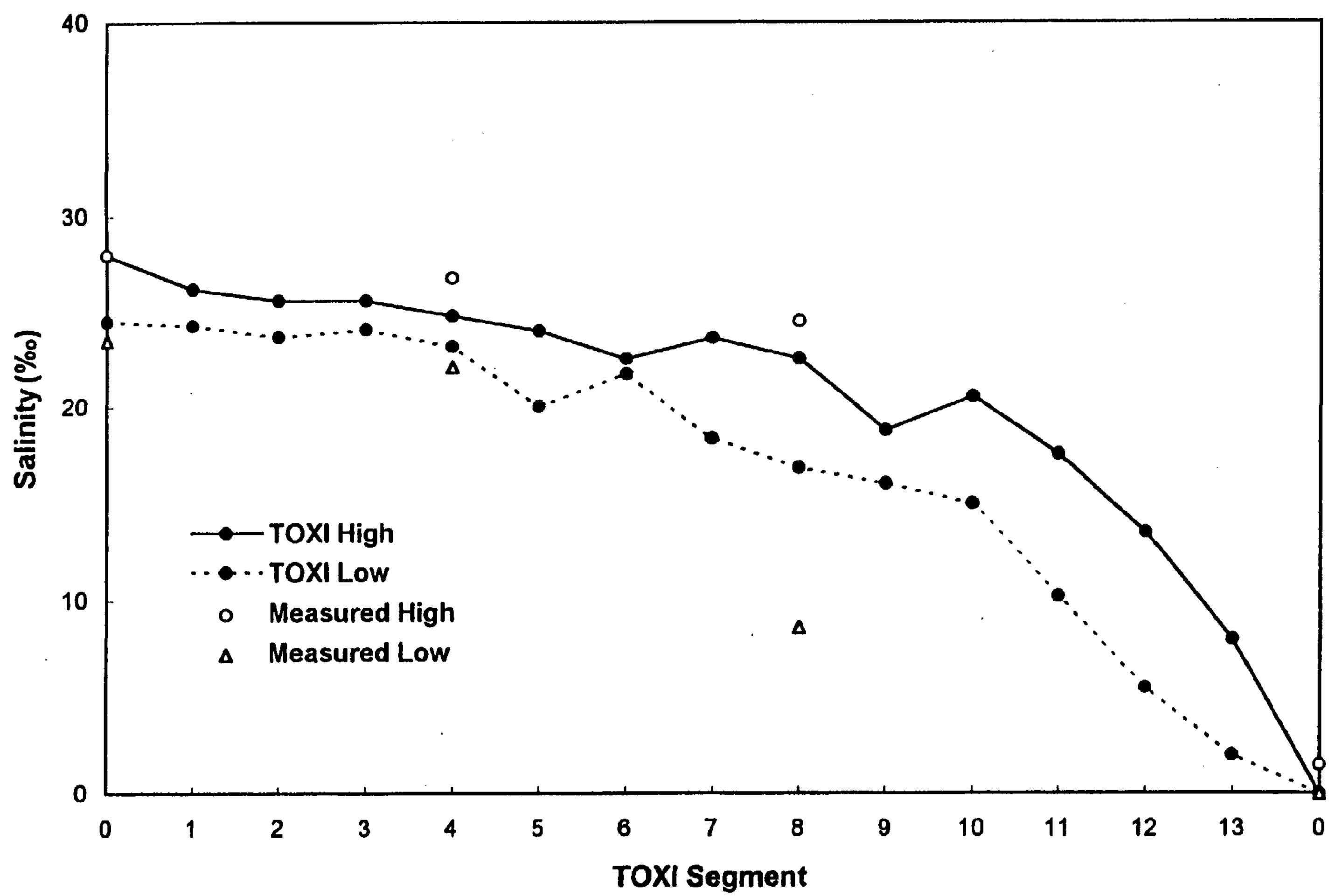

Fig. 8 Computed and measured salinity during average discharge.

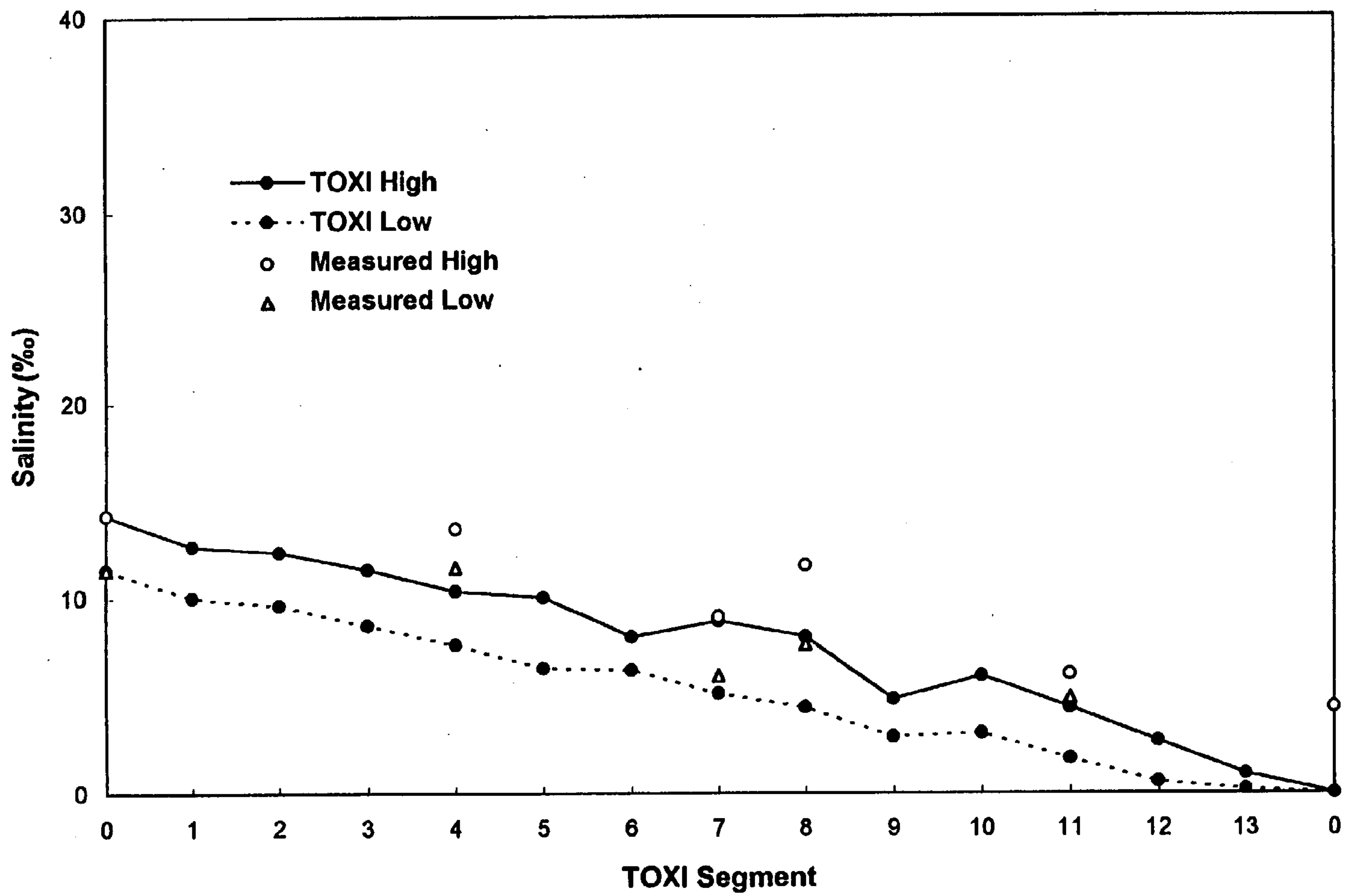

Fig. 9 Computed and measured salinity during high discharge.

BACTERIA

APPLICATIONS

Three important and representative TOXI applications to bacteria distribution are presented in this report out of the wide range of loadings and environmental conditions considered. In the applications presented here, predictions are made for fecal coliforms (FCs), while simulations for enterococci and c. perfringens are done similarly. The included analyses are for steady state conditions, a time variable point source release at the POTW and a rainfall event.

The steady state simulations were for the average discharge conditions discussed in the HYDRODYNAMICS and SALINITY DISTRIBUTION AND MIXING sections. Tributary input and boundary conditions were specified using field data from the Jones and Langan (1993) study. Sensitivity analyses were performed by varying loadings, bacteria decay rate and mixing parameters. Predictions are compared with average yearly data and data obtained on specific dates.

A simulation for a short (4 hour) accidental release at the POTW illustrates the transient flushing characteristics of the estuary. This analysis was specifically requested by Chris Nash of the NH Coastal Program for use in assessing the impact of a release on nearby shellfish beds. Model predictions are also compared with those of CORMIX - an effluent discharge model applied to the accidental release problem.

The rainfall event simulation computed the response to a once-a-year, 2.5 inch rain storm over an 8 hour period. The highly time variable tributary discharge impact was specified based on field data supplied by Schmidt (1981). This problem was suggested at a meeting of the Oyster River Watershed Committee, and results were presented to that group on April 25, 1996.

STEADY STATE

Loadings and Boundary Conditions

TOXI was applied to the problem of calculating FC distribution while the system was subject to steady state tides and mean freshwater input. Current and sea levels used were computed by DYNHYD for average tributary discharge conditions as discussed in the HYDRODYNAMICS section. Mixing coefficients were those calibrated for salinity distribution under the same average discharge conditions (see SALINITY DISTRIBUTION AND MIXING).

Boundary conditions were taken as the geometric average end point conditions for 1992-93 provided by Jones and Langan (1993). Specifically, a concentration of 8 FCs/100 ml was used at the mouth, and 79.2 FCs/100ml was used at the head. Initial conditions were arbitrarily taken to be 20 FCs/100ml. Tributary loadings at Bunker, Johnson and Beards Creeks were determined by multiplying the Jones and Langan (1993) concentration by the corresponding tributary discharge. Since this information was not available for Deer Meadow, yet this source was observed to be important, its loading had to be estimated. Based on similar watershed area and shore development characteristics, the Deer Meadow loading was taken to be the same as Bunker Creek.

Using these values the TOXI input file was formulated and is listed in the Appendix. Bacterial decay is not included in the base run application, though decay is considered in the sensitivity analysis. The resulting predicted time series for selected stations is shown on Fig 10. It is seen that steady state tidal response is quickly achieved, and the general trend is increasing FC concentration from mouth to head. Since most field measurements were taken at low tide, low tide values (peaks in the time series) are plotted as a function of longitudinal position in Fig 11.

Sensitivity Analysis

The sensitivity of the Oyster River system to changes in user-specified parameters was investigated by varying input values. Tributary FC loadings were doubled with very little increase in predicted Oyster River concentration. Main channel increases were less than 15%, while concentration increases in Bunker and Johnson Creeks were less than 35%. Halving the loadings induced an essentially negligible decrease. Thus the simulated system is relatively insensitive to intermediate loadings and is dominated by the mouth boundary condition at Little Bay, the head boundary condition at the main stem dam and mixing processes in between.

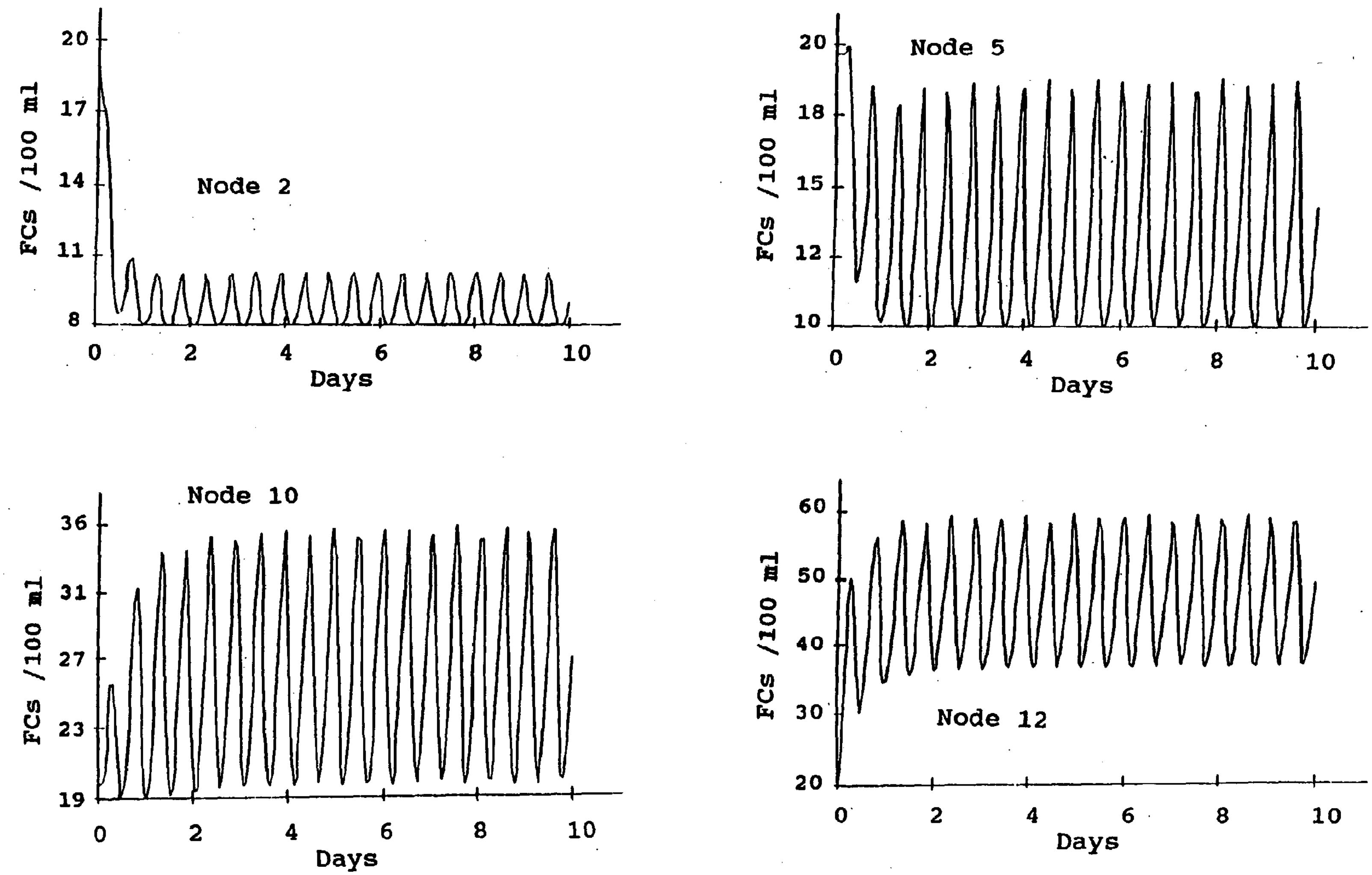

Fig. 10 FCs at selected nodes during average conditions.

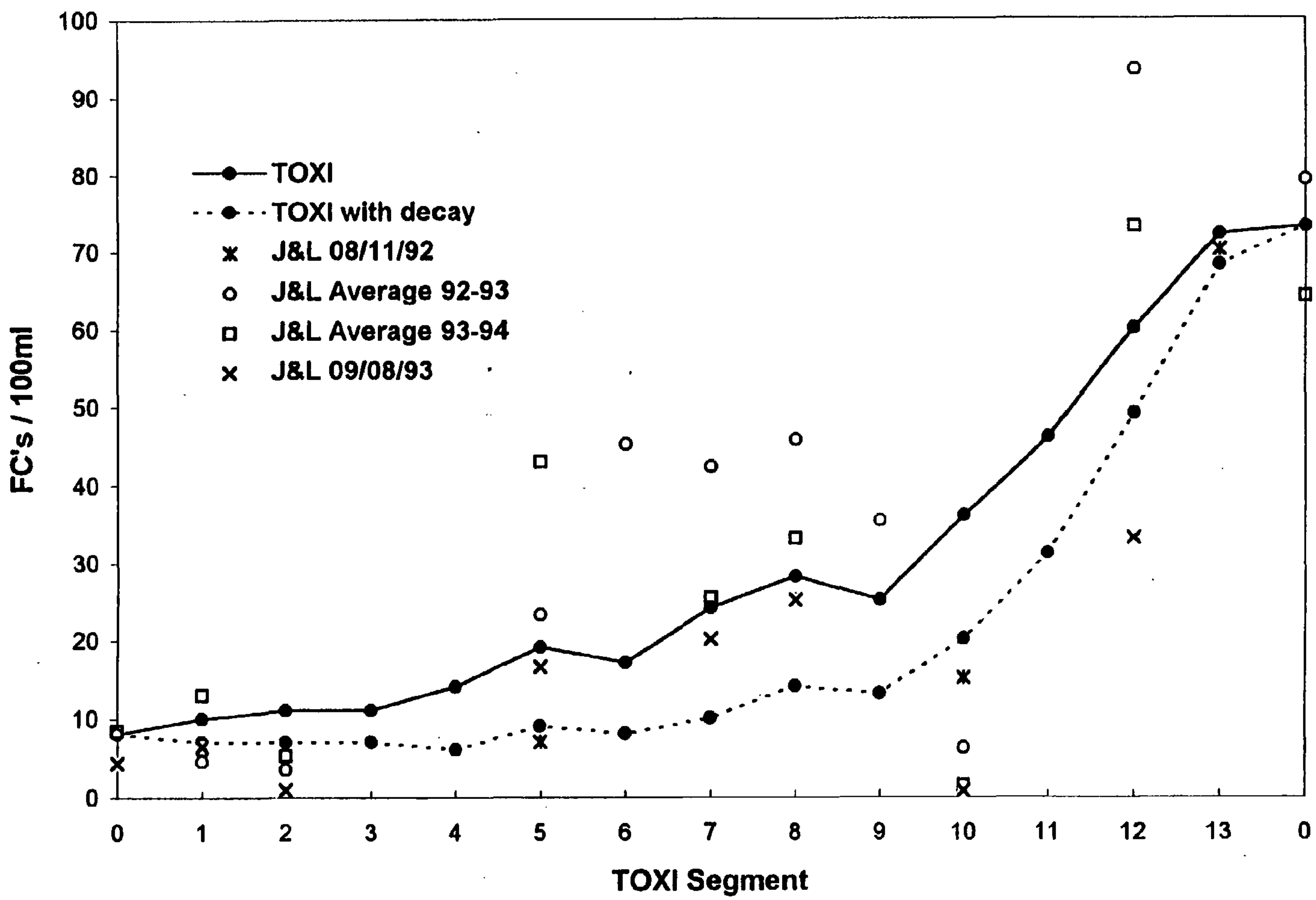

Fig. 11 FC concentration at low tide during average conditions.

The sensitivity of bacteria prediction to decay was investigated by using the decay term in the TOXI model and employing a range of decay coefficients. Results for a decay coefficient of 0.693 /d , corresponding to a half-life of one day, are shown in Fig. 11. It is seen that decay processes can decrease river bacteria concentration significantly.

The effects of changing mixing coefficients was also considered. This was motivated by physical reasoning which suggested that mixing exchange by turbulence and dispersion would be reduced at low tide. Mixing coefficients were varied by up to an order of magnitude, and time variable mixing coefficients were introduced in which low tide mixing exchange was made negligible. Predicted bacteria concentration did increase somewhat when dilution processes were inhibited by decreased mixing, but the effects are small compared to the changes in mixing coefficient required. Since legitimate mixing coefficients had been established by calibrating for salinity and the sensitivity of FC prediction to changes in mixing coefficients was small, the original mixing coefficients were retained without adjustment.

Comparison to Field Data

Low tide predictions were compared with FC concentration measurements obtained by Jones and Langan (1993, 1994). Shown on Fig. 11 are yearly, geometrically averaged data for 1992-93 and 1993-94, as well as the specific dates of August 11, 1992 and

September 8, 1993 (for which runoff conditions were assumed to be commensurate).

The general trends are in approximate agreement, though there is observed to be some scatter in the data. There also appears to be some anomalous behavior particularly in the vicinity of the POTW (node 10) and Beards Creek (node 12). The decrease in measured concentration near the POTW was explained by Jones and Langan (1993) to be the result of chlorinated effluent disinfecting the area. Chlorination has since been discontinued, so no effort was made to modify TOXI to account for this process. The peak concentration measurements in the vicinity of Beards Creek were attributed to a leaking sewage pipe. Durham is undergoing a program to replace old, leaky pipes including this one. The high 1993-94 value at node 5 was due to an unusually large fall "event" which biased the yearly geometrically averaged data at that point.

Other high values near nodes 6, 7 and 8 could be due to direct, unaccounted for loadings. The area is highly developed with houses having private septic systems. Seepage at low tide, when river water volume is extremely small, can have a pronounced effect on sampling. In addition, these sites were not sampled as often as some of the other sites, and annual mean values could be biased by the time period when most samples were collected. Also, the measured values could reflect elevated concentrations near sources in water not well-mixed.

Since model computations did not exhibit a general trend of over-predicting bacteria concentration, decay coefficients were not introduced as a calibration parameter. In fact, introducing significant decay would instead make the predictions worse. Time scales associated with mixing, dilution and flushing appear to be quite short, so it is not surprising that a conservative mixing approach provides the best match with observations.

POTW ACCIDENTAL RELEASE

The TOXI model was applied to the problem of an untreated sewage release from the Durham waste water treatment plant on the Oyster River. R. Langan of JEL and H. Gallagher, a graduate student in the UNH Civil Engineering Department, were consulted regarding the specific problem to be considered that would yield the most useful information. They had previously applied the effluent discharge and mixing model CORMIX to several scenarios related to the sewage release problem. CORMIX provides a detailed analysis of the plume distribution but does not take into account the time and spatial variation of the tidal current as do the WASP models.

The problem identified as being most relevant was a 4 hour release of fecal coliform (FC) starting at high slack water. Bacteria were assumed conservative (ie., no decay) in the TOXI application. Other input data were:

POTW discharge rate = 1.3 million gallons per day

FC concentration = 2×10^6 FC per 100 ml

Average tributary freshwater discharge conditions

No FC concentration in tributary input and at the Little Bay boundary.

Results included a prediction for maximum concentration at the mouth segment of 88 FC/100 ml with a maximum concentration of 180 FC/100 ml for the next segment upriver from the mouth. The time of the first maximum level was low tide (= 6.2 hours from the start of release at high water). Significant peaks occurred at the next 2 low tides as well. After 6 low tides, bacteria concentration was diluted significantly. Thus the "flushing time" for cleansing the system is about 3 days.

This compares with a corresponding CORMIX application (with decay) predicting a peak of 421 FC/100 ml at the mouth at 4.17 hours after the start of release at high water. The higher CORMIX prediction can be attributed in part to differences between point and spatially-averaged quantities. The CORMIX model predicted a plume extending over only a third of the channel width. The concentration within the plume varies transversely, and the peak centerline concentration is given. WASP, on the other hand, calculates concentrations which are spatially-averaged over full segment volumes. Other contributing factors include dilution by clean Little Bay water at the mouth and reduced transport just downriver from the POTW due to shallow water depths.

As a check on the WASP computations, an overall mass balance analysis for the entire system was completed. Results indicated that total FC amounts could be accounted for in the predicted distribution.

Overall, the comparison may be interpreted as indicating that CORMIX predicts the worst case that can be expected. The WASP simulation, on the other hand, provides evidence that peak concentrations may actually be diluted significantly by mixing processes. The question remains as to what level of mixing best describes "typical" or special conditions.

RAINFALL EVENT

TOXI was used to simulate bacteria distribution during a once-a-year rainfall event. The storm consisted of 2 1/2 inches of rain falling during an 8 hour period following a dry weather period. Base conditions before and after the storm were the "average conditions" described in the STEADY STATE section. The main concern was the transient behavior of FC distribution as the storm passed through.

In applying WASP, particular attention was paid towards specifying the time varying tributary freshwater discharge and the time varying tributary bacteria loading. All other parameters could remain at "average conditions" values.

Freshwater discharge was obtained from Schmidt (1981) who gauged Pettee Brook during a specific storm corresponding to that being analyzed here. Discharge rates for the Oyster River main stem and other tributaries were inferred using their relative watershed areas.

FC loadings were specified by multiplying time varying tributary discharge by an assumed concentration. In specifying concentration, consideration was given to the argument that runoff should wash more pollutants into the feeding streams thus increasing bacteria concentration especially during initial discharge conditions. The counter-process is dilution from increased freshwater flow later during the event. Both observations have been made in the Oyster River. A compromise concentration value representing no change from average conditions was used in the model. The time varying loadings are consequently due directly to volume rates of flow changes. In addition, it was assumed that the POTW was functioning properly and did not release storm related bacteria.

TOXI predictions, shown on Fig. 12, clearly show the transient nature of the Oyster River bacteria concentration response. Values increased substantially by approximately 30 %. The largest effects were in the creek tributaries, and changes were more pronounced going upriver. Fecal coliform concentration returned to normal after 4 days. Thus the "flushing time" of about 3 days after the event is consistent with that determined in the accidental release simulation.

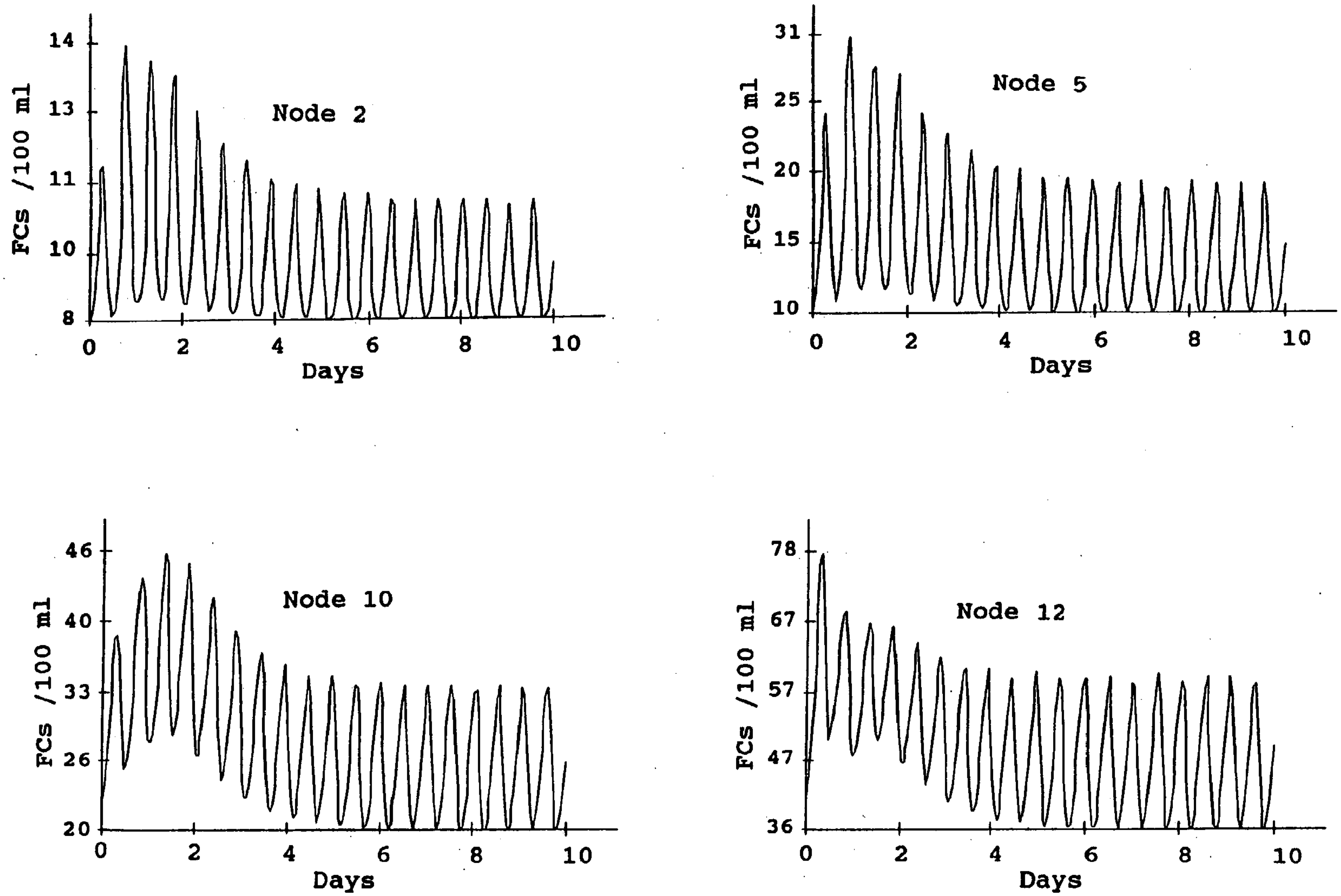

Fig. 12 FC concentration at selected nodes during a rain event.

DISSOLVED OXYGEN AND NUTRIENTS

DISSOLVED OXYGEN

The dissolved oxygen (DO) component of this study was undertaken mainly by J. Dubois as a Mechanical Engineering senior project under the supervision of M. R. Swift. Modeling methods and results are detailed in his senior project report (Dubois, 1996), while main points are summarized here.

DO field data taken at the same time as the Jones and Langan (1993, 1994) studies consisted of results of a one year sampling program at stations distributed over the length of the tidal Oyster River. Great Bay Watch (1995) established a much longer DO data set for one station in the Oyster River which was sampled twice a month. Observations indicated concentrations on the order of 8 mg/l but with considerable variability. Schmidt (1981) measured BOD in Pettee Brook, which runs into Beard's Creek, as part of his Oyster River watershed modeling effort. He observed BOD concentrations varying from less than 25 mg/l to over 250 mg/l during the rainfall event discussed in the BACTERIA modeling chapter. Other than BOD loading due to runoff events and the potential for POTW loading, previous work did not reveal any dominant sources or sinks. Under normal conditions, DO fluctuates somewhat randomly in the vicinity of the saturation value.

Since the POTW is always a possible source of BOD, one modeling objective was to assess the impact of the POTW on DO in the tidal Oyster River. The major focus, however, was to apply WASP to a significant rainfall event to evaluate DO reduction from NPS runoff.

In both applications, the EUTRO component of the WASP suite of models was applied to the simulation of BOD and DO. Specifically, the Streeter-Phelps set of equations were selected to simulate the decay of BOD, the reduction of DO by BOD and the replenishment of DO by reaeration.

The first application involved determing the effects of the POTW during normal runoff conditions. The maximum DO deficit was calculated as 0.3 mg/l from an average DO concentration of about 8 mg/l. Even when the POTW BOD loading was increased by a factor of 10, the DO deficit at the POTW was on the order of 0.4 mg/l. These simulations, therefore, indicate that the point source POTW loading is not an important degrader of DO under normal conditions.

The rainfall event application corresponds to the same storm discussed in the BACTERIA chapter - a once-a-year storm consisting of 2 1/2 inches of rain in an 8 hour period. As in the bacteria modeling, DYNHYD was used to simulate current and surface elevation due to both tides and the time varying, tributary freshwater input. The time dependent tributary flow was inferred from data obtained from Schmidt (1981). This source also provided the time varying BOD concentration necessary to specify the tributary BOD loadings and model boundary conditions.

EUTRO predicted an extreme drop in DO at the head of the Oyster River (momentarily negligible) with a moderate reduction (1 mg/l deficit) at the mouth. DO drops were largest during the first 4 low tides with a return to normal conditions within 5 days of the start of the storm.

NUTRIENTS

Modeling Considerations

The nutrients modeled in this study were nitrogen and phosphorus, the two critical elements of nutrient NPS contamination. Nitrogen in the forms of ammonium (NH4) and nitrate (NO3) and phosphorus in the form of phosphate (PO4) were studied extensively by Jones and Langan (1994). Both concentrations in the river and loadings were measured. They found that the most important loading was due to the POTW with the remaining contributions distributed among the tributaries. No important sinks were discussed, while the effects of tidal advection and mixing processes could be identified from the data distribution.

In view of these observations, TOXI was applied to nitrogen and phosphorus using the measured loadings and boundary conditions at head and mouth but without decay. In each application TOXI was run for steady state tidal conditions over several cycles during a time of average freshwater discharge (see Appendix for input files). TOXI low tide predictions were then compared with yearly-averaged, measured low tide concentrations.

Nitrogen

Jones and Langan (1994) observed wildly fluctuating proportions of ammonium and nitrate in the effluent from the POTW, the principal source to the Oyster River. Total dissolved nitrogen (ammonium plus nitrate) was much more well-behaved, and loadings to the river were provided for this combination (rather than individual contributions). Thus TOXI was also applied to total dissolved nitrogen (NH4 + NO3). Loadings and boundary conditions were specified from the Jones and Langan (1994) report, and TOXI was run for average tributary freshwater discharge conditions. The TOXI input file is provided in the Appendix.

Predicted concentrations at low water are plotted in Fig. 13 along with data from Jones and Langan (1994) low water measurements. Other than at the POTW, general trends are consistent though there is some scatter. At the POTW, the measured concentration is much higher. This is because the sample was obtained from the effluent plume right at the outfall, while the WASP prediction represents an average over the entire segment volume and, therefore, should be less.

<u>Phosphorus</u>

Phosphate (PO4) was modeled, using TOXI, for average freshwater discharge conditions. Loadings and boundary conditions were specified from the Jones and Langan (1994) report, and the input file is provided in the Appendix.

Predicted and measured (yearly averaged) low tide concentrations are plotted on Fig. 14 for comparison. As in the

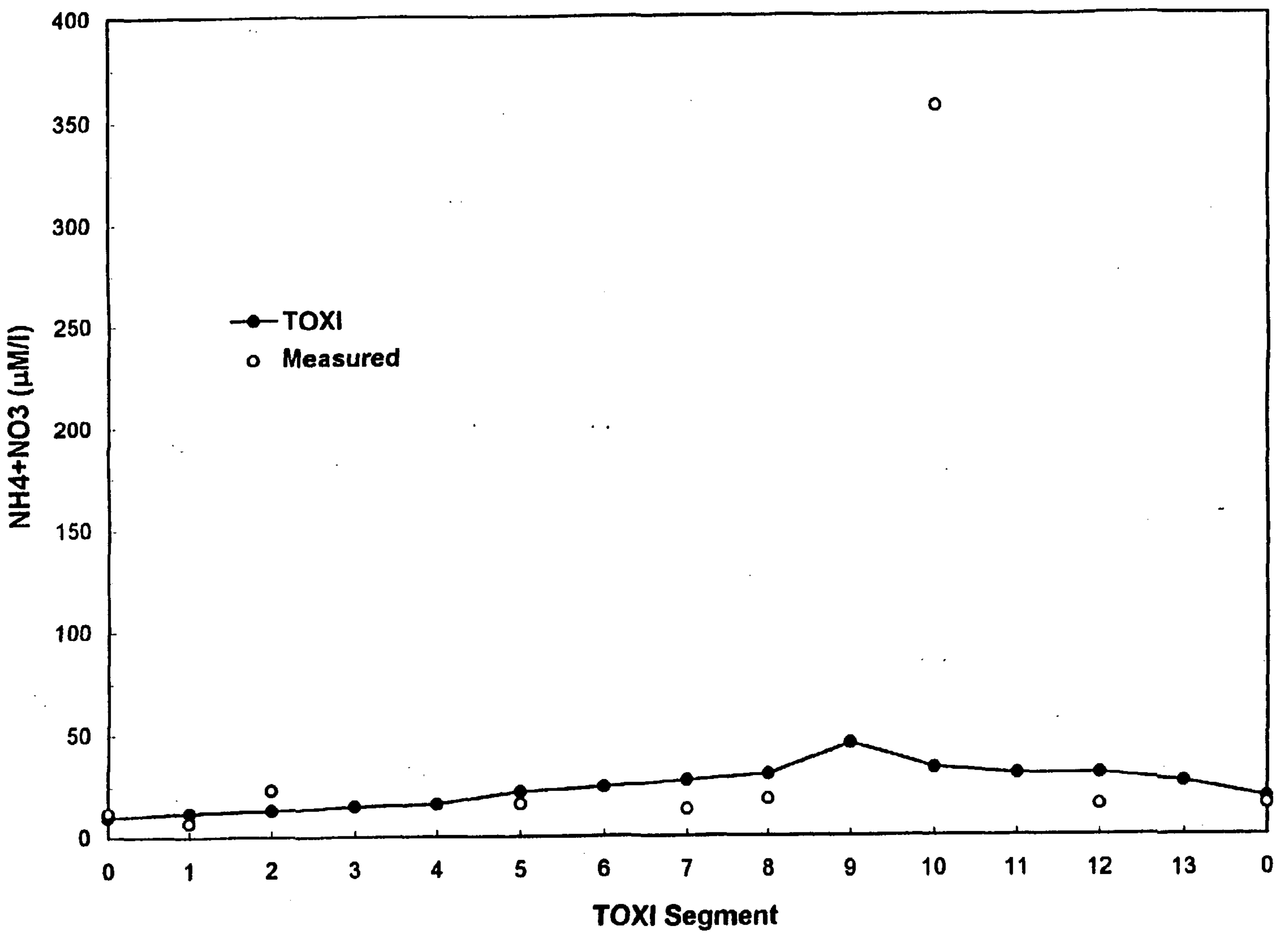

Fig. 13 Total dissolved nitrogen (NH4 + NO3) at low water during average discharge conditions.

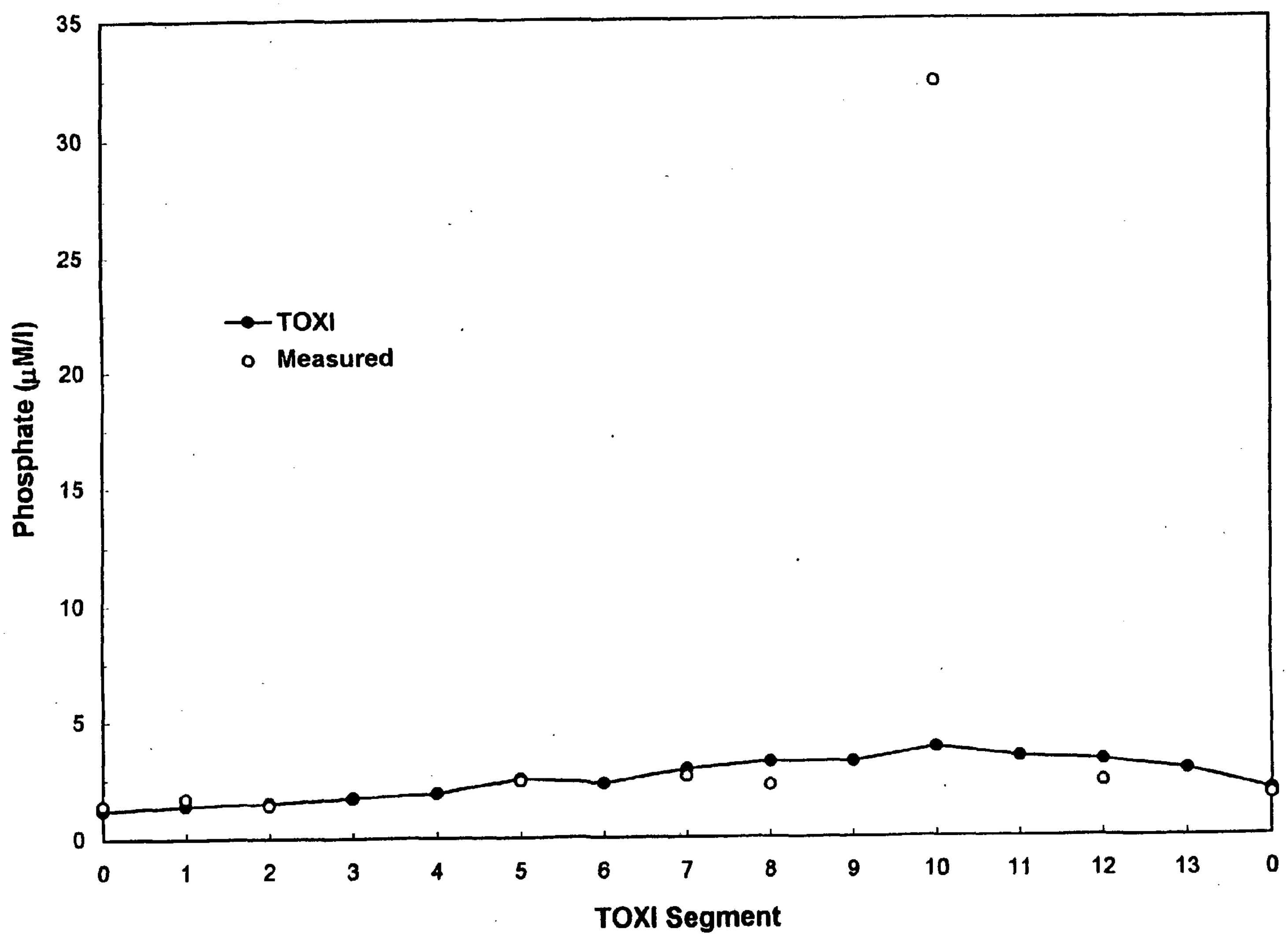

Fig. 14 Phosphate (PO4) at low water during average conditions.

case of total dissolved nitrogen, the general trends are consistent with reduced concentration away from the POTW and high concentration at the POTW. Measured concentration at the POTW is again higher than the predicted concentration due to the difference in what they represent. The measurement was taken at the outfall pipe and contains a portion of straight effluent, while the prediction is a spatial average including the surrounding water within the segment.

DISCUSSION

In completing the modeling work, the basic processes characterizing the tidal Oyster River have emerged. The system is dominated by tidal mixing and has a short 3 to 4 day residence time. Substances entering the system are quickly flushed out the mouth into the diluting waters of Little Bay. This type of mixing dynamics can also be expected to prevail in the other major tributaries to the Great Bay estuarine system.

Computed concentrations were not strongly sensitive to loadings or changes in mixing parameters that could be justified physically. End point (mouth and head) boundary conditions, on the other hand, are very important to predicting substance concentrations.

In comparing predictions with observations, generally good agreement was obtained, and overall trends and fundamental processes were reproduced. In comparing details, however, the difference in interpretation between field measurements and WASP predictions becomes important. Each field measurement was taken at a single point, usually in the main channel and often at a position giving an extreme value (near a pollution loading site, for example). The WASP predictions, on the other hand, are volume-averaged over a complete segment area and depth. WASP results were, therefore, less variable and extreme, but more representative of the segment as a whole.

Though the known tributary and point source pollution loadings were included in the simulations, there remains a possibility of additional loadings not accounted for. Ground water and private septic system seepage, for example, had not been quantified in previous field studies and consequently were not included in the calculations. These sources, however, could influence the field measurements which were done mostly at low water when tidal mixing and dilution are minimized. Here again, the measurement program was oriented towards identifying extreme (worst case) values, while the purpose of WASP is to compute representative averages made over larger volumes.

Despite the care necessary in interpreting results, WASP is sufficiently reliable for planning purposes. In fact, WASP was used in this way on two occasions during the study. "What if?" questions posed by the Office of State Planning and by the Oyster River Watershed Committee were answered through WASP simulations. Though WASP does not contain a watershed modeling component, normally previous information is available to estimate changes in tributary loading when considering a new application.

WASP does incorporate a comprehensive set of estuarine, bio/chemical equations and is widely-recognized as a standard in water quality modeling. Successful application depends on accurate observational data for calibration and loading, and the best data for this purpose are measurements which are characteristic and representative.

Our experience indicates that WASP is suitable for extension to the entire Great Bay system. Great Bay is normally well-mixed vertically, so 2-dimensional branching (in plan view) is appropriate for water column modeling. To complete a comprehensive model, sediment compartments can be added as well to account for bottom exchange processes. Though not necessary in the Oyster River because of its short residence time, exchanges with the bottom sediments become important when considering the entire estuarine system.

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APPENDIX

WASP input files for representative applications are listed in the following order:

DYNHYD hydrodynamic analysis during low discharge.

DYNHYD hydrodynamic analysis during average discharge.

DYNHYD hydrodynamic analysis during high discharge.

TOXI salinity analysis during low discharge.

TOXI salinity analysis during average discharge.

TOXI salinity analysis during high discharge.

TOXI FC analysis during average conditions.

TOXI total nitrogen analysis during average conditions.

TOXI phosphate analysis during average conditions.

DYNHYD hydrodynamic analysis during low discharge:

```
******Dynhyd5+  1995  6 DAY RUN FOR OYSTER RIVER MODEL Run 7***  OR7S.INP
******UNH Ocean Engineering - Low Flow - NOVEMBER 29 1995****
******PROGRAM CONTROL DATA*******
   15   14    0   15    5    1 0000   12 0000
*****PRINTOUT CONTROL DATA******
     0.00           1   15
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
*****SUMMARY CONTROL DATA*******
    1    1  0 0 12.5    6    3
**********JUNCTION DATA***********
    1       0.91   130000.      -4.10    1
    2       0.91   141000.      -3.90    1    2
    3       0.91   118000.      -3.60    2    3
    4       0.91    83800.      -3.70    3    4
    5       0.91    83800.      -3.40    4    5
    6       0.91   112000.      -2.10    5    6    7
    7       0.91    14600.      -1.30    6
    8       0.91   107000.      -1.90    7    8
    9       0.91    82600.      -1.80    8    9   10
   10       0.91    25300.      -1.30    9
   11       0.91    67600.      -2.30   10   11
   12       0.91    49800.      -2.00   11   12
   13       0.91    38700.      -1.50   12   13
   14       0.91    19500.      -1.40   13   14
   15       0.91    10700.      -1.40   14
**********CHANNEL DATA*********
    1       420.         78.      4.90     101.0       .040     .00000    1    2
    2       402.         95.      3.80     109.0       .040     .00000    2    3
    3       280.         75.      3.50     147.0       .040     .00000    3    4
    4       440.         68.      4.00     148.0       .040     .00000    4    5
    5       366.         58.      2.80     147.0       .040     .00000    5    6
    6       366.         10.      1.30     164.0       .040     .00000    6    7
    7       558.         63.      1.50     062.0       .040     .00000    6    8
    8       393.         48.      2.40     118.0       .040     .00000    8    9
    9       421.         15.      1.30     157.0       .040     .00000    9   10
   10       604.         30.      1.70     106.0       .040     .00000    9   11
   11       343.         30.      2.30     104.0       .040     .00000   11   12
   12       393.         25.      1.40     075.0       .040     .00000   12   13
   13       320.         25.      1.30     065.0       .040     .00000   13   14
   14       238.         25.      1.50     056.0       .040     .00000   14   15
**********CONSTANT INFLOW DATA********
    5
         7   -0.0020
        10   -0.0090
        11   -0.0447
        13   -0.0050
        15   -0.0280
**********VARIABLE INFLOW DATA*********
    0
**********SEAWARD BOUNDARY DATA********
    1
    1    1    1  100    0    0    0  1.0
     12.41        0.0
         0         0         0         0      0.91         0         0
*****************************************wind data***************************
    0
***** PRECIPITATION OR EVAPORATION DATA ***************************************
    0
***** JUNCTION GEOMETRY DATA **************************************************
    0
```

```
***** CHANNEL GEOMETRY DATA ************************************************************
    0
***** MAP TO WASP4 *********************************************************************
    0   15
    1    0
    2    1
    3    2
    4    3
    5    4
    6    5
    7    6
    8    7
    9    8
   10    9
   11   10
   12   11
   13   12
   14   13
   15    0
```

DYNHYD hydrodynamic analysis during average discharge:

```
******Dynhyd5+  1995 12 DAY RUN FOR OYSTER RIVER MODEL Run 6S** OR6S.INP
******UNH Ocean Engineering - SEPTEMBER 22 1995****
******PROGRAM CONTROL DATA*******
   15   14    0   15    5    1 0000   12 0000
*****PRINTOUT CONTROL DATA******
      0.00          1   15
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
*****SUMMARY CONTROL DATA*******
    1    1  0 0 12.5    6    3
**********JUNCTION DATA***********
    1       0.91   130000.      -4.10    1
    2       0.91   141000.      -3.90    1    2
    3       0.91   118000.      -3.60    2    3
    4       0.91    83800.      -3.70    3    4
    5       0.91    83800.      -3.40    4    5
    6       0.91   112000.      -2.10    5    6    7
    7       0.91    14600.      -1.30    6
    8       0.91   107000.      -1.90    7    8
    9       0.91    82600.      -1.80    8    9   10
   10       0.91    25300.      -1.30    9
   11       0.91    67600.      -2.30   10   11
   12       0.91    49800.      -2.00   11   12
   13       0.91    38700.      -1.50   12   13
   14       0.91    19500.      -1.40   13   14
   15       0.91    10700.      -1.40   14
**********CHANNEL DATA*********
    1       420.        78.       4.90     101.0       .040     .00000    1    2
    2       402.        95.       3.80     109.0       .040     .00000    2    3
    3       280.        75.       3.50     147.0       .040     .00000    3    4
    4       440.        68.       4.00     148.0       .040     .00000    4    5
    5       366.        58.       2.80     147.0       .040     .00000    5    6
    6       366.        10.       1.30     164.0       .040     .00000    6    7
    7       558.        63.       1.50     062.0       .040     .00000    6    8
    8       393.        48.       2.40     118.0       .040     .00000    8    9
    9       421.        15.       1.30     157.0       .040     .00000    9   10
   10       604.        30.       1.70     106.0       .040     .00000    9   11
   11       343.        30.       2.30     104.0       .040     .00000   11   12
   12       393.        25.       1.40     075.0       .040     .00000   12   13
   13       320.        25.       1.30     065.0       .040     .00000   13   14
   14       238.        25.       1.50     056.0       .040     .00000   14   15
**********CONSTANT INFLOW DATA********
    4
         7    -0.030
        10    -0.166
        13    -0.099
        15    -0.522
**********VARIABLE INFLOW DATA*********
    0
**********SEAWARD BOUNDARY DATA********
    1
    1    1    1  100    0    0    0  1.0
     12.41        0.0
         0        0        0        0      0.91        0        0
*******************************************wind data****************************
    0
***** PRECIPITATION OR EVAPORATION DATA ****************************************
    0
***** JUNCTION GEOMETRY DATA ***************************************************
    0
***** CHANNEL GEOMETRY DATA ****************************************************
```

```
     0
***** MAP TO WASP4 *****************************************************************
     0   15
     1    0
     2    1
     3    2
     4    3
     5    4
     6    5
     7    6
     8    7
     9    8
    10    9
    11   10
    12   11
    13   12
    14   13
    15    0
```

DYNHYD hydrodynamic analysis during high discharge:

```
******Dynhyd5+  1995 12 DAY RUN FOR OYSTER RIVER MODEL Run 8A***  OR8A.INP
******UNH Ocean Engineering High Flow - NOVEMBER 8 1995****
******PROGRAM CONTROL DATA*******
   15   14    0   15    5    1 0000    12 0000
*****PRINTOUT CONTROL DATA******
      0.00          1   15
    1    2    3    4    5    6    7    8    9   10   11   12   13   14   15
*****SUMMARY CONTROL DATA*******
    1    1  0 0 12.5    6    3
**********JUNCTION DATA***********
    1       0.91   130000.      -4.10    1
    2       0.91   141000.      -3.90    1    2
    3       0.91   118000.      -3.60    2    3
    4       0.91    83800.      -3.70    3    4
    5       0.91    83800.      -3.40    4    5
    6       0.91   112000.      -2.10    5    6    7
    7       0.91    14600.      -1.30    6
    8       0.91   107000.      -1.90    7    8
    9       0.91    82600.      -1.80    8    9   10
   10       0.91    25300.      -1.30    9
   11       0.91    67600.      -2.30   10   11
   12       0.91    49800.      -2.00   11   12
   13       0.91    38700.      -1.50   12   13
   14       0.91    19500.      -1.40   13   14
   15       0.91    10700.      -1.40   14
**********CHANNEL DATA*********
    1       420.        78.      4.90     101.0      .040    .00000    1    2
    2       402.        95.      3.80     109.0      .040    .00000    2    3
    3       280.        75.      3.50     147.0      .040    .00000    3    4
    4       440.        68.      4.00     148.0      .040    .00000    4    5
    5       366.        58.      2.80     147.0      .040    .00000    5    6
    6       366.        10.      1.30     164.0      .040    .00000    6    7
    7       558.        63.      1.50     062.0      .040    .00000    6    8
    8       393.        48.      2.40     118.0      .040    .00000    8    9
    9       421.        15.      1.30     157.0      .040    .00000    9   10
   10       604.        30.      1.70     106.0      .040    .00000    9   11
   11       343.        30.      2.30     104.0      .040    .00000   11   12
   12       393.        25.      1.40     075.0      .040    .00000   12   13
   13       320.        25.      1.30     065.0      .040    .00000   13   14
   14       238.        25.      1.50     056.0      .040    .00000   14   15
**********CONSTANT INFLOW DATA********
    4
         7    -0.115
        10    -0.637
        13    -0.379
        15    -2.000
**********VARIABLE INFLOW DATA*********
    0
**********SEAWARD BOUNDARY DATA********
    1
    1    1    1  100    0    0    0  1.0
     12.41        0.0
         0         0         0         0      0.91         0         0
*******************************************wind data****************************
    0
***** PRECIPITATION OR EVAPORATION DATA ******************************************
    0
***** JUNCTION GEOMETRY DATA *****************************************************
    0
***** CHANNEL GEOMETRY DATA ******************************************************
```

```
    0
***** MAP TO WASP4 *****************************************************************
    0   15
    1    0
    2    1
    3    2
    4    3
    5    4
    6    5
    7    6
    8    7
    9    8
   10    9
   11   10
   12   11
   13   12
   14   13
   15    0
```

TOXI salinity analysis during low discharge:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 11/30/95      FILE: ORT7S.INP
LINKED to OR7S.HYD
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC   DD HHMM       A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0    0 0000
   1    2    3   11   12   13
   1
  0.00625        10.
   1
 0.041667        10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1       1.0       1.0                           (water column diffusion)
  14
      382        210    0    1
      361        201    1    2
      263        140    2    3
      272        220    3    4
      162        183    4    5
       13        183    5    6
       95        279    5    7
      115        147    7    8
       20        421    8    9
       51        604    8   10
       69        343   10   11
       35        393   11   12
       33        320   12   13
       38        238   13    0
   2
    10.00         0.      10.00      365.
   0    1    1    1    1    1
   2    0        1.0   +    *    +    *    +    *    +    *    C: VOLUMES
   1.0000    1.0000
        1          0         1   620400       0       0       0       0
        2          0         1   436600       0       0       0       0
        3          0         1   318440       0       0       0       0
        4          0         1   293300       0       0       0       0
        5          0         1   229600       0       0       0       0
        6          0         1    21170       0       0       0       0
        7          0         1   203300       0       0       0       0
        8          0         1   148680       0       0       0       0
        9          0         1    40480       0       0       0       0
       10          0         1   128440       0       0       0       0
       11          0         1    94620       0       0       0       0
       12          0         1    52245       0       0       0       0
       13          0         1    26325       0       0       0       0
   3    1    OR7S.HYD  +    *    +    *    +    *    +    *    D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *    E: BOUNDARIES
     1.00        1.00                                    Salinity
   1   13
    30.37   0.00000     30.40   0.04309     30.32   0.08618     30.16   0.12927
    29.96   0.17236     29.76   0.21545     29.63   0.25854     29.60   0.30163
    29.68   0.34472     29.83   0.38781     30.04   0.43090     30.24   0.47399
    30.37   0.51708
  13   13
    12.85   0.00000     13.27   0.04309     12.28   0.08618     10.14   0.12927
     7.43   0.17236      4.87   0.21545      3.15   0.25854      2.73   0.30163
     3.72   0.34472      5.86   0.38781      8.57   0.43090     11.13   0.47399
    12.85   0.51708
        2                                                          S1
```

```
     1.00         1.00
    1   13
     00.00     0.00000       00.00     0.04309       00.00     0.08618       00.00     0.12927
     00.00     0.17236       00.00     0.21545       00.00     0.25854       00.00     0.30163
     00.00     0.34472       00.00     0.38781       00.00     0.43090       00.00     0.47399
     00.00     0.51708
   13   13
     00.00     0.00000       00.00     0.04309       00.00     0.08618       00.00     0.12927
     00.00     0.17236       00.00     0.21545       00.00     0.25854       00.00     0.30163
     00.00     0.34472       00.00     0.38781       00.00     0.43090       00.00     0.47399
     00.00     0.51708
         0    +    *    +    *    +    *    +    *    +    *    F: LOADS
         0                                                 S1
         0                                               (NPS LOADS)
         0    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
    *    +    *    +    *    +    *    +    *    +    *    +    *     H: CONSTANT
   GLOBALS         0         *         *         *         *
  CHEMICAL1        0         *         *         *         *
  SEDIMENT1        0         *         *         *         *
         0    +    *    +    *    +    *    +    *    +    *    I:TIME FUNCTIONS
C1                                          0   0.0           40   J:INITIAL Cs
    1:      30.30        1.0   2:      28.90       1.0   3:      27.40        1.0
    4:      26.00        1.0   5:      24.50       1.0   6:      23.10        1.0
    7:      21.60        1.0   8:      20.20       1.0   9:      18.70        1.0
   10:      17.30        1.0  11:      15.80       1.0  12:      14.40        1.0
   13:      12.90        1.0
S1                                          0   0.0           40
    1:      00.00        0.0   2:      00.00       0.0   3:      00.00        0.0
    4:      00.00        0.0   5:      00.00       0.0   6:      00.00        0.0
    7:      00.00        0.0   8:      00.00       0.0   9:      00.00        0.0
   10:      00.00        0.0  11:      00.00       0.0  12:      00.00        0.0
   13:      00.00        0.0
```

TOXI salinity analysis during average discharge:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 11/27/95      FILE:ORT6FS.INP
LINKED to OR6S.HYD
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC   DD HHMM        A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0    0 0000
   1    2    3   11   12   13
   1
  0.00625        10.
   1
 0.041667        10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1       1.0       1.0                         (water column diffusion)
  14
       382       42.0    0    1
       361       40.2    1    2
       263       28.0    2    3
       272       44.0    3    4
       162        366    4    5
        13        366    5    6
        95        558    5    7
       115        393    7    8
        20        421    8    9
        51        604    8   10
        69        343   10   11
        35        393   11   12
        33        320   12   13
        38        238   13    0
   2
   10.00         0.      10.00       365.
   0    1    1    1    1    1
   2    0       1.0    +    *    +    *    +    *    +    *      C: VOLUMES
   1.0000    1.0000
         1          0         1   620400         0         0         0         0
         2          0         1   436600         0         0         0         0
         3          0         1   318440         0         0         0         0
         4          0         1   293300         0         0         0         0
         5          0         1   229600         0         0         0         0
         6          0         1    21170         0         0         0         0
         7          0         1   203300         0         0         0         0
         8          0         1   148680         0         0         0         0
         9          0         1    40480         0         0         0         0
        10          0         1   128440         0         0         0         0
        11          0         1    94620         0         0         0         0
        12          0         1    52245         0         0         0         0
        13          0         1    26325         0         0         0         0
   3    1     OR6S.HYD  +    *    +    *    +    *    +    *      D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *      E: BOUNDARIES
    1.00       1.00                                       Salinity
   1   13
   27.85   0.00000     27.98   0.04309     27.66   0.08618     26.96   0.12927
   26.06   0.17236     25.22   0.21545     24.65   0.25854     24.51   0.30163
   24.83   0.34472     25.54   0.38781     26.44   0.43090     27.28   0.47399
   27.85   0.51708
  13   13
   00.00   0.00000     00.00   0.04309     00.00   0.08618     00.00   0.12927
   00.00   0.17236     00.00   0.21545     00.00   0.25854     00.00   0.30163
   00.00   0.34472     00.00   0.38781     00.00   0.43090     00.00   0.47399
   00.00   0.51708
       2                                                            S1
```

```
     1.00         1.00
  1    13
    00.00     0.00000        00.00     0.04309        00.00     0.08618        00.00     0.12927
    00.00     0.17236        00.00     0.21545        00.00     0.25854        00.00     0.30163
    00.00     0.34472        00.00     0.38781        00.00     0.43090        00.00     0.47399
    00.00     0.51708
 13    13
    00.00     0.00000        00.00     0.04309        00.00     0.08618        00.00     0.12927
    00.00     0.17236        00.00     0.21545        00.00     0.25854        00.00     0.30163
    00.00     0.34472        00.00     0.38781        00.00     0.43090        00.00     0.47399
    00.00     0.51708
         0     +     *     +     *     +     *     +     *     +     *     F: LOADS
         0                                                      S1
         0                                                    (NPS LOADS)
         0     +     *     +     *     +     *     +     *     +     *     G: PARAMETERS
    *    +     *     +     *     +     *     +     *     +     *     +     *     H: CONSTANT
  GLOBALS            0           *           *           *           *
CHEMICAL1            0           *           *           *           *
SEDIMENT1            0           *           *           *           *
         0     +     *     +     *     +     *     +     *     +     *   I:TIME FUNCTIONS
C1                                                0  0.0        40   J:INITIAL Cs
   1:        27.85        1.0   2:        23.04       1.0   3:      21.40        1.0
   4:        18.82        1.0   5:        16.68       1.0   6:      13.41        1.0
   7:        13.41        1.0   8:        11.11       1.0   9:      11.11        1.0
  10:         7.58        1.0  11:         5.57       1.0  12:       3.27        1.0
  13:         0.00        1.0
S1                                                0  0.0        40
   1:        00.00        0.0   2:        00.00       0.0   3:      00.00        0.0
   4:        00.00        0.0   5:        00.00       0.0   6:      00.00        0.0
   7:        00.00        0.0   8:        00.00       0.0   9:      00.00        0.0
  10:        00.00        0.0  11:        00.00       0.0  12:      00.00        0.0
  13:        00.00        0.0
```

TOXI salinity analysis during high discharge:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 11/10/95      FILE: ORT8E.INP
LINKED to OR8A.HYD HIGH FLOW
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC   DD HHMM       A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0    0 0000
   1    2    3   11   12   13
   1
 0.00625       10.
   1
0.041667       10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1      1.0       1.0                               (water column diffusion)
  14
       382       210    0    1
       361       201    1    2
       263       140    2    3
       272       220    3    4
       162       183    4    5
        13       183    5    6
        95       279    5    7
       115       147    7    8
        20       421    8    9
        51       604    8   10
        69       343   10   11
        35       393   11   12
        33       320   12   13
        38       238   13    0
   2
   10.00       0.      10.00      365.
   0    1    1    1    1    1
   2    0      1.0    +    *    +    *    +    *    +    *     C: VOLUMES
   1.0000   1.0000
        1          0         1    620400         0         0         0         0
        2          0         1    436600         0         0         0         0
        3          0         1    318440         0         0         0         0
        4          0         1    293300         0         0         0         0
        5          0         1    229600         0         0         0         0
        6          0         1     21170         0         0         0         0
        7          0         1    203300         0         0         0         0
        8          0         1    148680         0         0         0         0
        9          0         1     40480         0         0         0         0
       10          0         1    128440         0         0         0         0
       11          0         1     94620         0         0         0         0
       12          0         1     52245         0         0         0         0
       13          0         1     26325         0         0         0         0
   3    1     OR8A.HYD  +    *    +    *    +    *    +    *    D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *    E: BOUNDARIES
     1.00      1.00                                     Salinity
   1   13
    14.08   0.00000     14.19   0.04309     13.93   0.08618     13.36   0.12927
    12.65   0.17236     11.97   0.21545     11.52   0.25854     11.41   0.30163
    11.67   0.34472     12.23   0.38781     12.95   0.43090     13.63   0.47399
    14.08   0.51708
  13   13
     0.00   0.00000      0.00   0.04309      0.00   0.08618      0.00   0.12927
     0.00   0.17236      0.00   0.21545      0.00   0.25854      0.00   0.30163
     0.00   0.34472      0.00   0.38781      0.00   0.43090      0.00   0.47399
     0.00   0.51708
        2                                                      S1
```

```
    1.00       1.00
  1   13
   00.00    0.00000      00.00    0.04309      00.00    0.08618      00.00    0.12927
   00.00    0.17236      00.00    0.21545      00.00    0.25854      00.00    0.30163
   00.00    0.34472      00.00    0.38781      00.00    0.43090      00.00    0.47399
   00.00    0.51708
 13   13
   00.00    0.00000      00.00    0.04309      00.00    0.08618      00.00    0.12927
   00.00    0.17236      00.00    0.21545      00.00    0.25854      00.00    0.30163
   00.00    0.34472      00.00    0.38781      00.00    0.43090      00.00    0.47399
   00.00    0.51708
       0    +    *    +    *    +    *    +    *    +    *    F: LOADS
       0                                                 S1
       0                                              (NPS LOADS)
       0    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
  *    +    *    +    *    +    *    +    *    +    *    +    *      H: CONSTANT
  GLOBALS        0         *         *         *         *
 CHEMICAL1       0         *         *         *         *
 SEDIMENT1       0         *         *         *         *
       0    +    *    +    *    +    *    +    *    +    *  I:TIME FUNCTIONS
C1                                          0  0.0         40  J:INITIAL Cs
   1:     14.00        1.0   2:      13.70     1.0   3:     13.30        1.0
   4:     13.00        1.0   5:      12.50     1.0   6:     12.00        1.0
   7:     11.50        1.0   8:      11.00     1.0   9:      9.30        1.0
  10:      7.60        1.0  11:       6.00     1.0  12:      3.00        1.0
  13:      0.00        1.0
S1                                          0  0.0         40
   1:     00.00        0.0   2:      00.00     0.0   3:     00.00        0.0
   4:     00.00        0.0   5:      00.00     0.0   6:     00.00        0.0
   7:     00.00        0.0   8:      00.00     0.0   9:     00.00        0.0
  10:     00.00        0.0  11:      00.00     0.0  12:     00.00        0.0
  13:     00.00        0.0
```

TOXI FC analysis during average conditions:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 05/24/96       FILE:ORT6GSC2.INP
LINKED to OR6S.HYD
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC    DD HHMM        A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0     0 0000
   1    2    3   11   12   13
   1
  0.00625        10.
   1
 0.041667        10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1       1.0       1.0                              (water column diffusion)
  14
      382        42.0    0    1
      361        40.2    1    2
      263        28.0    2    3
      272        44.0    3    4
      162         366    4    5
       13       10000    5    6
       95         558    5    7
      115         393    7    8
       20       10000    8    9
       51         604    8   10
       69         343   10   11
       35         393   11   12
       33         320   12   13
       38         238   13    0
    2
    10.00          0.      10.00      365.
   0    1    1    1    1    1
   2    0      1.0    +    *    +    *    +    *    +    *    C: VOLUMES
   1.0000     1.0000
        1          0         1   620400      0        0        0        0
        2          0         1   436600      0        0        0        0
        3          0         1   318440      0        0        0        0
        4          0         1   293300      0        0        0        0
        5          0         1   229600      0        0        0        0
        6          0         1    21170      0        0        0        0
        7          0         1   203300      0        0        0        0
        8          0         1   148680      0        0        0        0
        9          0         1    40480      0        0        0        0
       10          0         1   128440      0        0        0        0
       11          0         1    94620      0        0        0        0
       12          0         1    52245      0        0        0        0
       13          0         1    26325      0        0        0        0
   3    1     OR6S.HYD  +    *    +    *    +    *    +    *    D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *    E: BOUNDARIES
     1.00       1.00                                     Fecal Coliform
   1   13
   0.0800   0.00000   0.0800   0.04309   0.0800   0.08618   0.0800   0.12927
   0.0800   0.17236   0.0800   0.21545   0.0800   0.25854   0.0800   0.30163
   0.0800   0.34472   0.0800   0.38781   0.0800   0.43090   0.0800   0.47399
   0.0800   0.51708
  13   13
  0.79200   0.00000  0.79200   0.04309  0.79200   0.08618  0.79200   0.12927
  0.79200   0.17236  0.79200   0.21545  0.79200   0.25854  0.79200   0.30163
  0.79200   0.34472  0.79200   0.38781  0.79200   0.43090  0.79200   0.47399
  0.79200   0.51708
        2                                                         S1
```

```
   1.00       1.00
 1   13
  00.00    0.00000      00.00   0.04309      00.00   0.08618      00.00   0.12927
  00.00    0.17236      00.00   0.21545      00.00   0.25854      00.00   0.30163
  00.00    0.34472      00.00   0.38781      00.00   0.43090      00.00   0.47399
  00.00    0.51708
13   13
  00.00    0.00000      00.00   0.04309      00.00   0.08618      00.00   0.12927
  00.00    0.17236      00.00   0.21545      00.00   0.25854      00.00   0.30163
  00.00    0.34472      00.00   0.38781      00.00   0.43090      00.00   0.47399
  00.00    0.51708
      4    +    *    +    *    +    *    +    *    +    *    F: LOADS
    1.0       1.0
 6    2
  1.172        0.     1.172      365.                           C1
 7    2
  1.172        0.     1.172      365.                           C1
 9    2
  5.063        0.     5.063      365.                           C1
12    2
  2.232        0.     2.232      365.                           C1
      0                                              S1
      0                                            (NPS LOADS)
      0    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
 *    +    *    +    *    +    *    +    *    +    *    +    *    H: CONSTANT
  GLOBALS         0         *         *         *         *
CHEMICAL1         0         *         *         *         *
SEDIMENT1         0         *         *         *         *
      0    +    *    +    *    +    *    +    *    +    *   I:TIME FUNCTIONS
C1                                          0   0.0    5.70E10   J:INITIAL Cs
   1:      0.2000       1.0   2:     0.2000       1.0   3:     0.2000      1.0
   4:      0.2000       1.0   5:     0.2000       1.0   6:     0.2000      1.0
   7:      0.2000       1.0   8:     0.2000       1.0   9:     0.2000      1.0
  10:      0.2000       1.0  11:     0.2000       1.0  12:     0.2000      1.0
  13:      0.2000       1.0
S1                                          0   0.0          40
   1:       00.00       0.0   2:      00.00       0.0   3:      00.00      0.0
   4:       00.00       0.0   5:      00.00       0.0   6:      00.00      0.0
   7:       00.00       0.0   8:      00.00       0.0   9:      00.00      0.0
  10:       00.00       0.0  11:      00.00       0.0  12:      00.00      0.0
  13:       00.00       0.0
```

TOXI total nitrogen analysis during average conditions:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 07/31/96      FILE:ORT6GSC6.INP
LINKED to OR6S.HYD
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC   DD HHMM       A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0    0 0000
   1    2    3   11   12   13
   1
  0.00625        10.
   1
 0.041667        10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1       1.0       1.0                                   (water column diffusion)
  14
       382      42.0    0    1
       361      40.2    1    2
       263      28.0    2    3
       272      44.0    3    4
       162       366    4    5
        13     10000    5    6
        95       558    5    7
       115       393    7    8
        20     10000    8    9
        51       604    8   10
        69       343   10   11
        35       393   11   12
        33       320   12   13
        38       238   13    0
   2
    10.00        0.      10.00       365.
   0    1    1    1    1    1
   2    0       1.0    +    *    +    *    +    *    +    *     C: VOLUMES
   1.0000   1.0000
         1         0         1  620400         0         0         0         0
         2         0         1  436600         0         0         0         0
         3         0         1  318440         0         0         0         0
         4         0         1  293300         0         0         0         0
         5         0         1  229600         0         0         0         0
         6         0         1   21170         0         0         0         0
         7         0         1  203300         0         0         0         0
         8         0         1  148680         0         0         0         0
         9         0         1   40480         0         0         0         0
        10         0         1  128440         0         0         0         0
        11         0         1   94620         0         0         0         0
        12         0         1   52245         0         0         0         0
        13         0         1   26325         0         0         0         0
   3    1   OR6S.HYD   +    *    +    *    +    *    +    *    D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *    E: BOUNDARIES
    1.00      1.00                                         Fecal Coliform
   1   13
   0.0100  0.00000    0.0100  0.04309    0.0100  0.08618    0.0100  0.12927
   0.0100  0.17236    0.0100  0.21545    0.0100  0.25854    0.0100  0.30163
   0.0100  0.34472    0.0100  0.38781    0.0100  0.43090    0.0100  0.47399
   0.0100  0.51708
  13   13
  0.01820  0.00000   0.01820  0.04309   0.01820  0.08618   0.01820  0.12927
  0.01820  0.17236   0.01820  0.21545   0.01820  0.25854   0.01820  0.30163
  0.01820  0.34472   0.01820  0.38781   0.01820  0.43090   0.01820  0.47399
  0.01820  0.51708
        2                                                            S1
```

```
   1.00       1.00
 1   13
  00.00    0.00000     00.00    0.04309     00.00    0.08618     00.00    0.12927
  00.00    0.17236     00.00    0.21545     00.00    0.25854     00.00    0.30163
  00.00    0.34472     00.00    0.38781     00.00    0.43090     00.00    0.47399
  00.00    0.51708
13   13
  00.00    0.00000     00.00    0.04309     00.00    0.08618     00.00    0.12927
  00.00    0.17236     00.00    0.21545     00.00    0.25854     00.00    0.30163
  00.00    0.34472     00.00    0.38781     00.00    0.43090     00.00    0.47399
  00.00    0.51708
      4    +    *    +    *    +    *    +    *    +    *    F: LOADS
    1.0       1.0
 6   2
  0.268        0.     0.268      365.                             C1
 9   2
  1.678        0.     1.678      365.                             C1
10   2
  5.248        0.     5.248      365.                             C1
12   2
  1.147        0.     1.147      365.                             C1
      0                                                      S1
      0                                                     (NPS LOADS)
      0    +    *    +    *    +    *    +    *    +    *    G: PARAMETERS
  *   +    *    +    *    +    *    +    *    +    *    +    *    H: CONSTANT
 GLOBALS        0         *         *         *         *
CHEMICAL1       0         *         *         *         *
SEDIMENT1       0         *         *         *         *
      0    +    *    +    *    +    *    +    *    +    *   I:TIME FUNCTIONS
C1                                         0  0.0    5.70E10  J:INITIAL Cs
   1:    0.0100      1.0   2:    0.0100       1.0   3:    0.0100      1.0
   4:    0.0100      1.0   5:    0.0100       1.0   6:    0.0100      1.0
   7:    0.0100      1.0   8:    0.0100       1.0   9:    0.0100      1.0
  10:    0.0100      1.0  11:    0.0100       1.0  12:    0.0100      1.0
  13:    0.0100      1.0
S1                                         0  0.0         40
   1:     00.00      0.0   2:     00.00       0.0   3:     00.00      0.0
   4:     00.00      0.0   5:     00.00       0.0   6:     00.00      0.0
   7:     00.00      0.0   8:     00.00       0.0   9:     00.00      0.0
  10:     00.00      0.0  11:     00.00       0.0  12:     00.00      0.0
  13:     00.00      0.0
```

TOXI phosphate analysis during average conditions:

```
TEST OYSTER R TOXI INPUT FILE:  DATE: 08/05/96       FILE:ORT6GSC7.INP
LINKED to OR6S.HYD
NSEG NSYS ICFL MFLG JMAS NSLN INTY ADFC    DD HHMM        A:MODEL OPTIONS
  13    2    0    0    1    0    1  0.0     0 0000
   1    2    3   11   12   13
   1
  0.00625        10.
   1
 0.041667        10.
   0    1    1    1    1    1
   1    0    +    *    +    *    +    *    +    *    +    *    B:EXCHANGES
   1      1.0        1.0                             (water column diffusion)
  14
        382       42.0    0    1
        361       40.2    1    2
        263       28.0    2    3
        272       44.0    3    4
        162        366    4    5
         13      10000    5    6
         95        558    5    7
        115        393    7    8
         20      10000    8    9
         51        604    8   10
         69        343   10   11
         35        393   11   12
         33        320   12   13
         38        238   13    0
   2
   10.00         0.      10.00       365.
   0    1    1    1    1    1
   2    0      1.0    +    *    +    *    +    *    +    *      C: VOLUMES
   1.0000     1.0000
         1          0         1   620400         0         0         0         0
         2          0         1   436600         0         0         0         0
         3          0         1   318440         0         0         0         0
         4          0         1   293300         0         0         0         0
         5          0         1   229600         0         0         0         0
         6          0         1    21170         0         0         0         0
         7          0         1   203300         0         0         0         0
         8          0         1   148680         0         0         0         0
         9          0         1    40480         0         0         0         0
        10          0         1   128440         0         0         0         0
        11          0         1    94620         0         0         0         0
        12          0         1    52245         0         0         0         0
        13          0         1    26325         0         0         0         0
   3    1     OR6S.HYD    +    *    +    *    +    *    +    *      D: FLOWS
   0    1    1    1    1    1
        2    +    *    +    *    +    *    +    *    +    *      E: BOUNDARIES
    1.00       1.00                                       Fecal Coliform
   1   13
   0.0012    0.00000    0.0012   0.04309    0.0012   0.08618    0.0012   0.12927
   0.0012    0.17236    0.0012   0.21545    0.0012   0.25854    0.0012   0.30163
   0.0012    0.34472    0.0012   0.38781    0.0012   0.43090    0.0012   0.47399
   0.0012    0.51708
  13   13
  0.00190    0.00000   0.00190   0.04309   0.00190   0.08618   0.00190   0.12927
  0.00190    0.17236   0.00190   0.21545   0.00190   0.25854   0.00190   0.30163
  0.00190    0.34472   0.00190   0.38781   0.00190   0.43090   0.00190   0.47399
  0.00190    0.51708
        2                                                         S1
```

```
      1.00         1.00
    1    13
     00.00     0.00000        00.00     0.04309        00.00     0.08618        00.00     0.12927
     00.00     0.17236        00.00     0.21545        00.00     0.25854        00.00     0.30163
     00.00     0.34472        00.00     0.38781        00.00     0.43090        00.00     0.47399
     00.00     0.51708
   13    13
     00.00     0.00000        00.00     0.04309        00.00     0.08618        00.00     0.12927
     00.00     0.17236        00.00     0.21545        00.00     0.25854        00.00     0.30163
     00.00     0.34472        00.00     0.38781        00.00     0.43090        00.00     0.47399
     00.00     0.51708
         4     +    *    +    *    +    *    +    *    +    *     F: LOADS
       1.0       1.0
    6    2
    0.0187         0.      0.0187       365.                                  C1
    9    2
    0.0724         0.      0.0724       365.                                  C1
   10    2
    0.7260         0.      0.7260       365.                                  C1
   12    2
    0.0603         0.      0.0603       365.                                  C1
         0                                                       S1
         0                                                     (NPS LOADS)
         0     +    *    +    *    +    *    +    *    +    *     G: PARAMETERS
    *    +    *    +    *    +    *    +    *    +    *    +    *     H: CONSTANT
    GLOBALS        0         *         *         *         *
  CHEMICAL1        0         *         *         *         *
  SEDIMENT1        0         *         *         *         *
         0     +    *    +    *    +    *    +    *    +    *    I:TIME FUNCTIONS
                                                 0   0.0    5.70E10   J:INITIAL Cs
C1
    1:    0.0010       1.0    2:     0.0010        1.0    3:     0.0010        1.0
    4:    0.0010       1.0    5:     0.0010        1.0    6:     0.0010        1.0
    7:    0.0010       1.0    8:     0.0010        1.0    9:     0.0010        1.0
   10:    0.0010       1.0   11:     0.0010        1.0   12:     0.0010        1.0
   13:    0.0010       1.0
                                                 0   0.0        40
S1
    1:     00.00       0.0    2:      00.00        0.0    3:      00.00        0.0
    4:     00.00       0.0    5:      00.00        0.0    6:      00.00        0.0
    7:     00.00       0.0    8:      00.00        0.0    9:      00.00        0.0
   10:     00.00       0.0   11:      00.00        0.0   12:      00.00        0.0
   13:     00.00       0.0
```